Warping of the Recording Angle in Ambisonics

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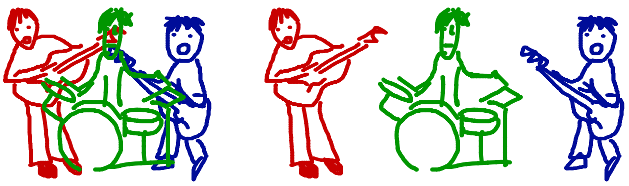
Abstract

When the main microphone of a recording picks up a musical scene at a recording angle that appears too wide or too narrow in the playback, it is very hard to correct this. To allow modifications in the post-processing of stereo, a sound recording engineer might use coincident microphone arrays as double-MS or the sound field microphone arrays. Higher order Ambisonics also uses array processing, but modification of the recording angle is uncommon, and it has been considered too complicated compared to stereo. This paper shows how to practically achieve warping of the recording angle in the processing of higher order Ambisonic recordings or productions. It concludes with an analytic recurrence scheme that is applicable and easy to implement.

Introduction

When the musicians appear too closely spaced in the play back of spatial audio material, the recording engineer needs editing tools for stretching the spatial image. The desired spatial audio editing effect is illustrated in Fig. 1.



(a) image too narrow **(b)** image corrected

Figure 1: Correction of a recording image that appeared to be too narrow.

Widening of a surround recording image for all directions simultaneously is not feasible without overlap or truncation. However, it is possible to widen the surround image around one spot, while compressing it on the opposite side. Gerzon et al. [1] proposed a transformation to achieve such warping for first order Ambisonic signals which was called “dominance effect”. Sontacchi investigated a similar transform for horizontal-only Ambisonics in his thesis [2]. Warping of the polar angle is best achieved by bilinear transformation of its cosine $\mu = \cos(\vartheta)$

$$\tilde{\mu} = \frac{\mu + \alpha}{1 + \alpha\mu}. \tag{1}$$

Fig. 2 illustrates the warping characteristics according to Eq. (1). Figs. 3 (a) and (b) geometrically show how positive and negative warping parameters α affect the surround image. Circles on a sphere were used for illustration, whereby the the gray dashed circles represent the original patterns and the colored solid circles are the warped ones. We describe warping of the zenith angle ϑ, i.e. around the North pole, only. The warping parameter α yields a shift of the equator by ϵ

$$\epsilon = \arcsin(\alpha). \tag{2}$$

Warping of any other spot in the surround image is achieved by pre- and post rotation. Figs. 4 (a) until (d) illustrate this procedure for warping on the horizon. The direction of interest is rotated to the North pole before warping, and rotated back afterwards.

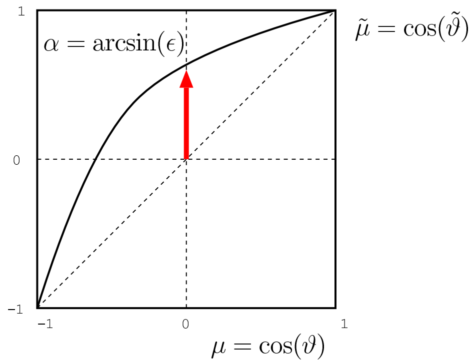
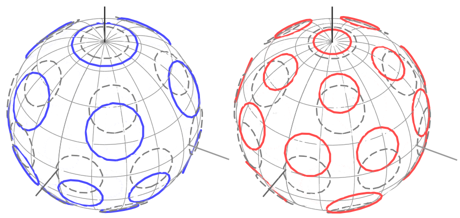


Figure 2: Mapping relation of bilinear warping.



(a) $\alpha < 0$ **(b)** $\alpha > 0$

Figure 3: Warping of a surround image by negative and positive α, illustrated by circles on a sphere.

Ambisonics

Ambisonics of orders up to N represent 3D surround sound using an expansion of the surround audio signal $f(\varphi, \vartheta, t)$ into spherical harmonics

$$f(\varphi, \vartheta, t) = \sum_{n=0}^{\mathrm{N}} \sum_{m=-n}^{n} Y_n^m(\varphi, \vartheta)\, \phi_{nm}(t), \tag{3}$$

whereby $Y_n^m(\varphi, \vartheta)$ are the spherical harmonics of order n, degree m, and $\phi_{nm}(t)$ are the expansion coefficients. The warped version of the signal $f(\varphi, \tilde{\vartheta}, t)$ with modified angle $\tilde{\vartheta}$ can also be expressed by the spherical harmonics

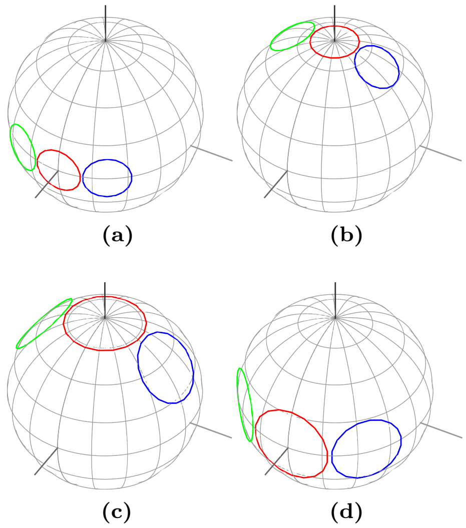


Figure 4: Horizontal warping by pre and post rotation.

$\tilde{\mathrm{N}}(m,\epsilon)$	0°	5°	10°	15°	20°	25°	30°
$m=0$	3	5	5	6	6	7	8
$m=1$	3	5	5	6	6	7	7
$m=2$	3	5	5	6	6	7	7
$m=3$	3	4	5	5	6	6	7

Table 1: Required order $\tilde{\mathrm{N}}$ for warping an $\mathrm{N}=3$ order Ambisonic signal by warping angles $\epsilon=\arcsin(\alpha)$ is shown, depending on the index m of the Legendre-functions. As a criterion, the re-expansion coefficients for normalized functions below $\frac{N_n^m}{N_{n'}^m}\,|w_{n'n}^m| > -30dB$ were omitted for all n.

using different coefficients

$$f(\varphi,\tilde{\vartheta},t)=\sum_{n=0}^{\tilde{\mathrm{N}}}\sum_{m=-n}^{n} Y_n^m(\varphi,\vartheta)\,\tilde{\phi}_{nm}(t). \qquad (4)$$

Note that the our representation of warping uses unnormalized spherical harmonics to keep the presented expressions simple; normalization is re-introduced in Eq. (6). The expansion order $\tilde{\mathrm{N}}>\mathrm{N}$ of the warped signal depends on the warping angle ϵ, cf. Tab. 1.

The warped Ambisonic signals are elegantly obtained by a weighted sum of the original Ambisonic signals

$$\tilde{\phi}_{n'}^m=\sum_n w_{n'n}^m\,\phi_n^m. \qquad (5)$$

A new way of calculating $w_{n'n}^m$ by applying the recurrence relations derived in [3] is presented after the coming section.

In order to convert the warping coefficients to be applicable to normalized Ambisonic signals, the normalization constants N_n^m need to be involved in this way

$$w_{n'n}^{m,(\mathrm{normalized})}=w_{n'n}^m\,\frac{N_n^m}{N_{n'}^m}. \qquad (6)$$

Magnitude Pre-Emphasis

Sources widened by warping are represented with increased energy which is proportional to their growth. In order to stabilize the loudness, the surround signal must be weighted accordingly before warping. This is achieved by

$$f(\varphi,\vartheta,t)\cdot g(\varphi,\vartheta)=\sum_{n=0}^{\mathrm{N}}\sum_{m=-n}^{n} Y_n^m(\varphi,\vartheta)\,\phi_n^m(t), \qquad (7)$$

$$g(\vartheta)=\frac{1+\alpha\cos(\vartheta)}{\sqrt{1+\alpha^2}}. \qquad (8)$$

For strong warping this operation increases the required order by 1. The corresponding modification of the Ambisonic signals has been derived in [3] and includes thinkable normalization here

$$\phi_n^m(t)=N_n^m\frac{\alpha\,\frac{n+m}{2n+1}\frac{\hat{\phi}_{n+1}^m(t)}{N_{n+1}^m}+\frac{\hat{\phi}_n^m(t)}{N_n^m}+\alpha\,\frac{n-m+1}{2n+1}\frac{\hat{\phi}_{n-1}^m(t)}{N_{n-1}^m}}{\sqrt{1+\alpha^2}}, \qquad (9)$$

whereby $\phi_n^m(t)$ are the coefficients of the pre-emphasized surround signal and $\hat{\phi}_n^m(t)$ are the original coefficients.

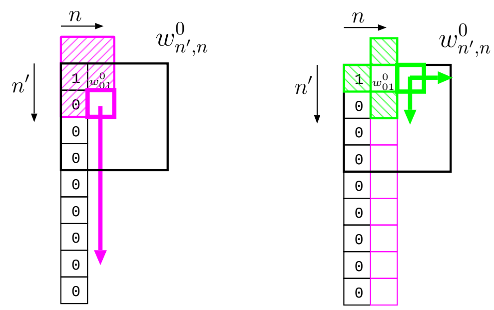
Warping Coefficients

Initialization. Some warping coefficients for $m=0$ can be initialized by simple expressions according to [3]

$$w_{n'0}^0=\tfrac{2n'+1}{2}\int_{-1}^{1} P_{n'}^0(\mu)\,d\mu=\delta_{n',0}\,, \qquad (10)$$

$$\begin{aligned} w_{0,1}^0 &= \tfrac{1}{2}\int_{-1}^{1}\tfrac{\mu+\alpha}{1+\alpha\mu}\,d\mu \\ &= \tfrac{\alpha^2-1}{2\alpha}\left(\ln(1+\alpha)-\ln(1-\alpha)\right)+\tfrac{1}{\alpha}\,. \end{aligned} \qquad (11)$$

All other coefficients can be calculated by applying the recurrences in the following order, cf. Figs. 5 and 6:



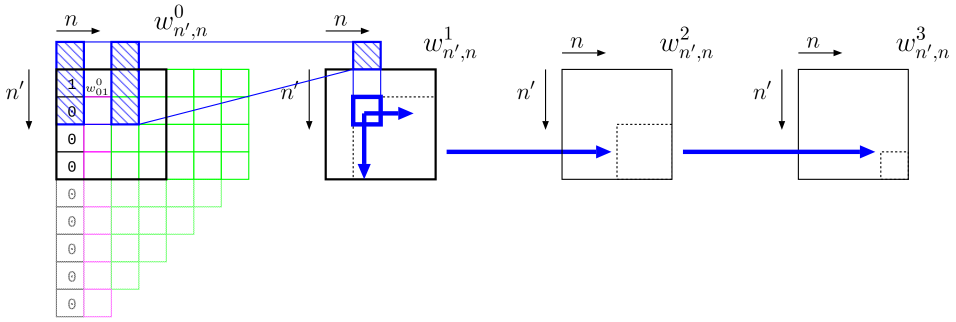
(a) Initialization and recurrence 1 **(b)** Recurrence 2

Figure 5: Initialization, Recurrence 1, and 2.

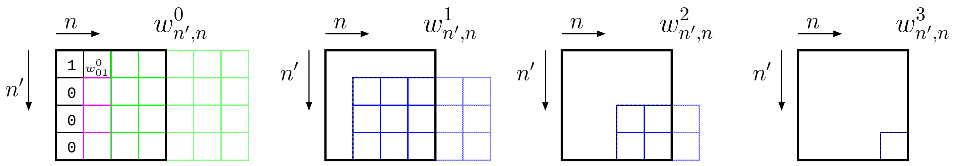
Recurrence 1 and stabilization. The first recurrence delivers coefficients for $m=0$ and $n=1$, cf. Fig. 5 (a). However it is not always numerically stable. There is an estimate of the values produced by the first recurrence,

$$\hat{w}_{n'+1,1}^0=(-1)^{n'}1.3\,(0.0235\,\epsilon^{7.1})^{n'/7}\,\cos\epsilon, \qquad (12)$$

which has been found by regression of the filter coefficients on a double-logarithmic scale. If actual recurrence diverges the coefficients are replaced by the estimate values, as expressed by Eq. (13).



(a) Recurrence 3



(b) Full set of resulting coefficients

Figure 6: Recurrence 3 and the set of coefficients obtained by all recurrence relations.

$$w^0_{n'+1,1} = \begin{cases} -\frac{2n'+3}{\alpha\,(n'+1)} w^0_{n',1} - \frac{n'(2n'+3)}{(n'+1)(2n'-1)} w^0_{n'-1,1} + \frac{1}{\alpha}\, w^0_{n'+1,0} + \frac{2n'+3}{n'+1}\, w^0_{n',0} + \frac{n'(2n'+3)}{\alpha\,(n'+1)(2n'-1)} w^0_{n'-1,0} \\ \hat{w}^0_{n'+1,1} \qquad \text{if } |w^0_{n'+1,1}| > |\hat{w}^0_{n'+1,1}| \text{ and } n' > 0 \end{cases} \tag{13}$$

$$w^0_{n',n+1} = w^0_{n',n-1} - \frac{(n'+1)(n'+2)(2n+1)}{n(n+1)(2n'+3)} w^0_{n'+1,n} + \frac{n'(n'-1)(2n+1)}{n(n+1)(2n'-1)} w^0_{n'-1,n} \tag{14}$$

$$\begin{aligned} w^m_{n'+1,n} = \frac{2n'+3}{\sqrt{1-\alpha^2}(n'+m)(n'+m+1)} \Bigg(& -\alpha \frac{(n-m+1)(n-m+2)(n'+m)}{(2n+1)(2n'+3)} w^{m-1}_{n'+1,n+1} - \frac{(n-m+1)(n-m+2)}{2n+1} w^{m-1}_{n',n+1} \\ & + \alpha \frac{(n+m-1)(n+m)(n'+m)}{(2n+1)(2n'+3)} w^{m-1}_{n'+1,n-1} + \frac{(n+m-1)(n+m)}{(2n+1)} w^{m-1}_{n',n-1} \\ & - \alpha \frac{(n-m+1)(n-m+2)(n'-m+1)}{(2n+1)(2n'-1)} w^{m-1}_{n'-1,n+1} + \alpha \frac{(n+m-1)(n+m)(n'-m+1)}{(2n+1)(2n'-1)} w^{m-1}_{n'-1,n-1} + \sqrt{1-\alpha^2} \frac{(n'-m)(n'-m+1)}{2n'-1} w^m_{n'-1,n} \Bigg) \end{aligned} \tag{15}$$

Recurrence 2. The second recurrence, given in Eq. (14), is numerically not as critical as the first one, and it is applied to find the required coefficients for $m = 0$. In order to obtain suitably many values for recurrence 3, recurrence 2 is applied for all n' up to $\tilde{\mathrm{N}} + \mathrm{N} + \mathrm{N} - 1 - 1 - m$.

Recurrence 3. The last recurrence, given in Eq. (15), is numerically the least critical of all three presented ones. It is applied to obtain the coefficients for all $m \neq 0$.

Conclusion

This paper discussed warping of 3D surround Ambisonic signals, its aim and application. We contributed new recurrence equations to compute the warping coefficients without any matrix inversion. The equations have been obtained from our previous work by selection of stable recurrences and additional stabilization.

Acknowledgments

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