DBAP - DISTANCE-BASED AMPLITUDE PANNING

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ABSTRACT

Most common techniques for spatialization require the listener to be positioned at a "sweet spot" surrounded by loudspeakers. For practical concert, stage, and installation applications such layouts may not be desirable. Distance-based amplitude panning (DBAP) offers an alternative panning-based spatialization method where no assumptions are made concerning the layout of the speaker array nor the position of the listener. DBAP is implemented both as an external for Max/MSP and as a module for the Jamoma Modular framework.

1. INTRODUCTION

Multichannel and surround sound reproduction is becoming common for both consumer applications as well as musical and artistic purposes. A number of spatialization techniques exist for virtual positioning of sound sources using an array of loudspeakers. These often assume that the position of the listener is known and fixed, and that the speakers are surrounding the listener either on a two-dimensional ring or a three-dimensional sphere. Examples of such speaker layouts and spatialization techniques are stereo panning, ITU 5.1 surround [4], further extended industrial multi-channel configurations [17], vector-based amplitude panning (VBAP) [14], and first- and higher-order ambisonics [3, 13].

Wave field synthesis (WFS) and Virtual Microphone Control (ViMiC) [10] are noticeable exceptions to the aforementioned "sweet spot" restriction.

WFS reproduces signals in a large listening area. The spatial properties of the acoustical scene can be perceived correctly by an arbitrarily large number of listeners regardless of their position inside this area [19]. Due to the high number of loudspeakers required, WFS might be impractical to use for financial reasons and time constraints unless one is working on a site where a permanent setup resides.

ViMiC incorporates distance-based signal delays between speakers, simulation of microphone patterns, early reflections, and surface absorption. This makes it relatively CPU-intensive. Thus ViMiC may require a dedicated computer for spatialization or restrictions on the number of loudspeakers used as compared to other techniques.

For real-time music and sound purposes, the low CPU requirements of matrix-based spatialization techniques make them popular choices. VBAP as well as ambisonics are readily available for use in common software environments for real-time processing such as Max/MSP [16, 18, 8], but they require that the listeners are restricted to a relatively small listening area surrounded by loudspeakers arranged in a circle or sphere. These requirements may not be feasible or desired in practical applications.

Distance-based amplitude panning (DBAP) is a matrix-based spatialization technique that takes the actual positions of the speakers in space as the point of departure, while making no assumptions as to where the listeners are situated. This makes DBAP useful for a number of real-world situations such as concerts, stage productions, installations[6], and museum sound design where predefined geometric speaker layouts may not apply.

2. DISTANCE-BASED AMPLITUDE PANNING

2.1. Fundamentals

Distance-based amplitude panning (DBAP) extends the principle of equal intensity panning from a pair of speakers to a loudspeaker array of any size, with no *a priori* assumptions about their positions in space or relative to each other. For simplicity, the method will be discussed using a two-dimensional model. This can be readily extended to three dimensions.

The Cartesian coordinates of a virtual source is given as (x_s, y_s). For a model with N speakers, the position of the ith speaker is given as (x_i, y_i). The distance d_i from a source to each of the speakers is

$$d_i = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2} \qquad \text{for } 1 \leq i \leq N . \quad (1)$$

For simplicity, the source is presumed as having unity amplitude. DBAP then makes two assumptions. The first is

that intensity is to be constant regardless of the position of the virtual source. This can be considered an extension of the principle of constant intensity stereo panning to multiple channels. If the amplitude of the ith speaker is v_i, this implies

$$I = \sum_{i=1}^{N} v_i^2 = 1 \; . \tag{2}$$

Secondly, it is assumed that all speakers are active at all times, and the relative amplitude of the ith speaker relates to the distance from the virtual source as

$$v_i = \frac{k}{d_i^a} \; , \tag{3}$$

where k is a coefficient depending on the position of the source and all speakers, while a is a coefficient calculated from the rolloff R in decibels per doubling of distance:

$$a = \frac{R}{20 \log_{10} 2} \tag{4}$$

A rolloff of $R = 6$ dB equals the inverse distance law for sound propagating in a free field. For closed or semi-closed environments R will generally be lower, in the range 3-5 dB, and depend on reflections and reverberation [2] (pp. 84-88). Equation (4) then represents a simplified description of attenuation with distance, but simulation of reflections and reverberation is anyway beyond the scope of an amplitude-panning based spatialization method.

Combining equations (2) and (3) k can be found as:

$$k = \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{1}{d_i^{2a}}}} \tag{5}$$

2.2. Spatial Blur

If the virtual source is located at the exact position of one of the loudspeakers, (5) will cause a division by zero. Combining equations (3) and (5) we get

$$v_j = \frac{1}{\sum_{i=1}^{N} \frac{d_j^{2a}}{d_i^{2a}}} \tag{6}$$

From this it can be shown that

$$\lim_{d_j \to 0} v_i = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases} \tag{7}$$

When the virtual source is located at the exact position of one of the loudspeakers, only that speaker will be emitting sound. This may cause unwanted changes in spatial spread and coloration of a virtual source in a similar way as observed for VBAP [15]. To adjust for this *spatial blur* $r_s \geq 0$ is introduced in equation (1):

$$d_i = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2 + r_s^2} \tag{8}$$

In two dimensions blur can be understood as a vertical displacement between source and speakers. The larger r gets, the less the source will be able to gravitate towards one speaker only. Practical experience indicates that there is a limit to the amount of blur that can be applied, or the precedence effect [5] will come into play, causing the perceived direction of the source to gravitate towards the speaker(s) closest to the listener.

In the implementations of DBAP discussed in section 3.1 the blur coefficient is normalized, using the covariance of distance from centre of loudspeaker rig to loudspeakers as scaling factor, in order to make the blur coefficient less sensitive to changes in size of loudspeaker layouts.

2.3. Sources Positioned Outside the Field of Speakers

The model presented so far is not able to cater for sources located outside the field of speakers. As distance to the field increases, the relative difference in distance from source to each of the speakers diminishes, resulting in progressively less difference in levels between the speakers, much the same way as when increasing spatial blur. Compensating for this requires additional calculations.

First, the *convex hull* of the field of loudspeakers is calculated. In two dimensions the convex hull "is the shape taken by a rubber band stretched around nails bounded into the plane at each point" [9]. It is then determined if the source is outside the hull or not. If it is inside or on the boundary no additional steps need to be taken. If the source is located outside, then the projection of the source onto the boundary of the hull is calculated, defined as the point on the boundary with the shortest possible distance to the source. This source position is substituted for its projection in subsequent calculations. In addition, the distance from source to the convex hull is returned. This value can be used for optional added spatial processing such as gain attenuation, air filtering, Doppler effect, or gradual introduction of reverb with increasing distance from the hull.

2.4. Extending DBAP by Introducing Speaker Weights

DBAP can be further extended by introduction of a speaker weight w_i in equation 3:

$$v_i = \frac{k w_i}{d_i^a} \tag{9}$$

Equation 5 is then modified to:

$$k = \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{w_i^2}{d_i^{2a}}}} \tag{10}$$

This enables a source to be restricted to use a subset of speakers, opening up for several artistic possibilities. In installations or museum spaces speaker weights can be used to confine sources to restricted areas. One source might be present in one room only while another source is permitted to move between several or all rooms. Used with an Acousmonium[1] [1] speaker weights can restrict diffusion of sources to specific groups of speakers. This permits a spatial orchestration to be prepared or composed prior to performance, and then adjusted to the specific room used for performance. Speaker weights can be changed dynamically, allowing smooth transitions from one subset of speakers to another.

Finally, weights can be used to differentiate the spatial spread for each loudspeaker, as shown in figure 3, enabling individual topologies for each source.

3. IMPLEMENTATION AND VISUALIZATION

3.1. Implementation

DBAP is implemented as an external for the real-time multimedia graphical environment Max/MSP, written in C as part of Jamoma [12]. The external supports several independent sources. Input gain for each source can be controlled prior to the DBAP processing and sources can be muted. In addition, a Jamoma DBAP module is developed with a similar interface as other Jamoma spatialization modules such as VBAP, ambisonics and ViMiC, according to the SpatDIF initiative [11].

3.2. Visual Representations

A visual representation of the behavior of the algorithm has been developed, using gradients to illustrate the "predominance" zone of each speaker. This is also intended to offer intuitive interactive manipulation of source positions and parameters such as spatial blur, rolloff and speaker weights.
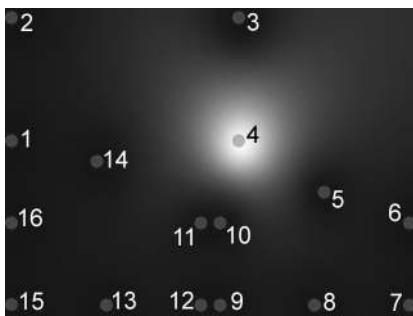

Figure 1. Representation of the levels 2D distribution for speaker 4. Points represent positions of the 16 speakers.

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[1]the Acousmonium is a large orchestra of speakers organized into instrumental groups according to sonic qualities and characteristics

The method for creating this visualization consists in creating a graphical map of level response for each loudspeaker as a 2D matrix of levels. For each pixel of this matrix, the pixel value is set to the squared amplitude returned by the DBAP algorithm if the source was located at this position. The visual result in figure 1 indicates the spatial response for one of the loudspeakers. The lighter pixels are positions where amplitudes are close to 1 and the darker pixels are positions where amplitudes are close to 0. As expected, the further away the source is from the loudspeaker the lower the amplitude.
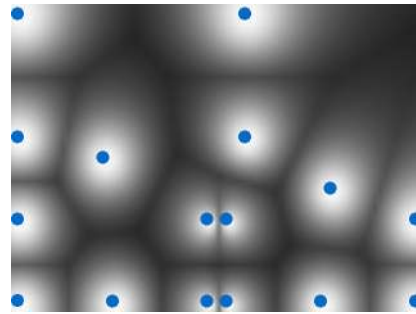

Figure 2. Representation of the 2D distribution of levels for all speakers.

A visualization of the response ranges for all speakers can be created by combining all figures of the same class as in fig. 1, and then finding the maximum amplitude for a given 2D-position. The graphical result, as in 2, shows segmented parts in space corresponding to every spatial zone of predominance for each loudspeaker. Here the darker pixels have to be explained as positions where the source is mixed equally between the closest loudspeakers.
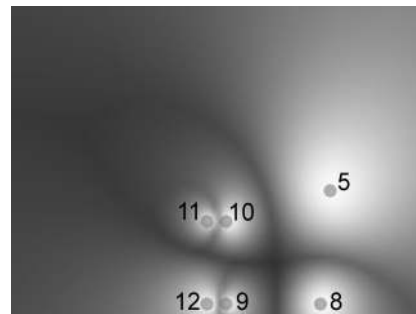

Figure 3. Representation of the 2D distribution of levels for 5 speakers only, with weights $[1.5, 1., 1., 1., 0.75, 1.2]$ for speakers $[5, 8, 9, 10, 11, 12]$.

These pictures are generated in realtime by the algorithm, and may serve as a user-interface for source positioning and DBAP parameter setting. Examples of this include use as back drops for mouse interaction or tactile-screen interaction.

4. CONCLUSIONS AND FURTHER WORK

DBAP offers a light-weight panning-based solution for spatialization using irregular loudspeaker layouts. The Jamoma module implementation makes DBAP available with an interface similar to other Jamoma modules for rendering spatial sound, enabling various techniques to be interchanged and compared.

Implementation of convex hulls and speaker weights remains to be combined (in the case of speakers subsets), and extended for three-dimensional loudspeaker layouts.

DBAP can also be used as a solution for dynamic routing of input sources to a spatial layout of effect processes. Instead of defining loudspeaker positions, the effects could be assigned positions in a data space, similarly to [7].

5. ACKNOWLEDGEMENTS

6. REFERENCES

[1] F. Bayle, *Musique acousmatique, propositions. . . . . . positions.* Bibliothèque de recherches musicales, INA-GRM-Buchet/Chastel, September 1993.

[2] A. F. Everest, *Master handbook of acoustics. 4th edition.* McGraw-Hill/TAB Electronics, September 2000.

[3] M. Gerzon, "Surround-sound psychoacoustics: Criteria for the design of matrix and descrete surround-sound systems." *Wireless World. Reprinted in An anthology of articles on spatial sound techniques, part 2: Multichannel audio technologies. Edited by F. Rumsey. Audio Engineering Society, Inc, 2006.*, pp. 483–486, December 1974.

[4] ITU, "Recommendation BS.775: Multi-channel stereophonic sound system with or without accompanying picture," International Telecommunications Union, Tech. Rep., 1993.

[5] R. Y. Litovsky, H. S. Colburn, W. A. Yost, and S. J. Guzman, "The precedence effect." *Journal of the Acoustical Society of America*, vol. 106, no. 4 Pt 1, pp. 1633–1654, October 1999.

[6] T. Lossius, "Controlling spatial sound within an installation art context," in *Proceedings of the 2008 International Computer Music Conference*, 2008.

[7] A. Momeni and D. Wessel, "Characterizing and controlling musical material intuitively with geometric models," in *Proceedings of the 2003 Conference on New Interfaces for Musical Expression (NIME-03), Montreal, Canada*, 2003.

[8] M. Neukom and J. Schacher, "Ambisonics equivalent panning," in *Proceedings of the 2008 International Computer Music Conference*, 2008.

[9] J. O'Rourke, *Computational Geometry in C. 2nd edition.* Cambridge University Press, 1998.

[10] N. Peters, T. Matthews, J. Braasch, and S. McAdams, "Spatial sound rendering in Max/MSP with ViMiC," in *Proceedings of the 2008 International Computer Music Conference*, 2008.

[11] N. Peters, "Proposing SpatDIF - The Spatial Sound Description Interchange Format," in *Proceedings of the 2008 International Computer Music Conference*, 2008.

[12] T. Place and T. Lossius, "Jamoma: A modular standard for structuring patches in Max," in *Proceedings of the 2006 International Computer Music Conference*, 2006.

[13] M. A. Poletti, "A unified theory of horizontal holographic sound systems," *Journal of the Audio Engineering Society*, vol. 48, no. 12, pp. 1155–1182, December 2000.

[14] V. Pulkki, "Virtual sound source positioning using vector base amplitude panning," *Journal of the Audio Engineering Society*, vol. 45(6), pp. 456–466, June 1997.

[15] ——, "Uniform spreading of amplitude panned virtual sources," in *Proceedings of the 1999 IEEE Workshop on Applications of Signal Processing to Audio and Acoustics. Mohonk Mountain House, New Paltz, New York.*, 1999.

[16] ——, "Generic panning tools for MAX/MSP," in *Proceedings of International Computer Music Conference 2000. Berlin, Germany, August, 2000.*, 2000, pp. 304–307.

[17] F. Rumsey, *Spatial Audio.* Focal Press, Oxford and Boston, June 2001.

[18] J. C. Schacher and P. Kocher, "Ambisonics spatialization tools for Max/MSP," in *Proceedings of the 2006 International Computer Music Conference*, 2006.

[19] S. Spors, H. Teutsch, A. Kuntz, and R. Rabenstein, *Sound Field Synthesis. In Audio Signal Processing for Next-Generation Multimedia Communication Systems.* Springer, 2004, pp. 323–344.