Robust Spatial Panning Functions for Nonuniform Loudspeaker Layouts

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Introduction

Panning functions are required if several loudspeakers are used to synthesise an impinging wave front from a virtual acoustic source for a distinct direction.

To obtain such panning functions, various ways are described in the literature. Using a vector base related to a selection of loudspeakers in a distinct spatial direction results in the vector base amplitude panning (VBAP) [1]. This more heuristically driven technology uses pairs of loudspeakers in the 2-dimensional and triples in the 3-dimensional case. The physically driven approach considered in this contribution incorporates all available loudspeakers simultaneously, and the panning functions strongly depend on the chosen loudspeaker positions. If these positions are geometrically irregular (e.g. in the typical 5-channel surround sound setup), a straight forward calculation leads to directional errors as well as a non-uniform power distribution. Panning functions that avoid these problems are termed as robust [6].

All known robust panning function approaches from the literature describe 2-dimensional scenarios, whereas in this contribution a 3-dimensional scenario is considered. A least-squares pressure matching design is described using an irregular spatial loudspeaker setup. The results using this new 3-dimensional approach are compared with the VBAP system in an informal listening test.

Loudspeaker Setup

The spatial arrangement of loudspeakers is referred to as *loudspeaker setup* in this paper. The 3D loudspeaker setup example considered here has 16 loudspeakers as it is shown in Figure 1. The positioning was chosen due to practical considerations, having four columns with three loudspeakers each and additional loudspeakers between these columns.

Vector Base Amplitude Panning

Vector Base Amplitude Panning (VBAP) is used to place virtual acoustic sources with an arbitrary loudspeaker setup where the same distance of the loudspeakers from the listening position is assumed [1]. VBAP uses three loudspeakers to place a virtual source in the 3D space. For each virtual source, a monophonic signal with different gains is fed to the loudspeakers to be used. The gains for the different loudspeakers are dependent on the position of the virtual source. VBAP is a geometric approach to calculate the gains of the loudspeaker signals for the panning between the loudspeakers.

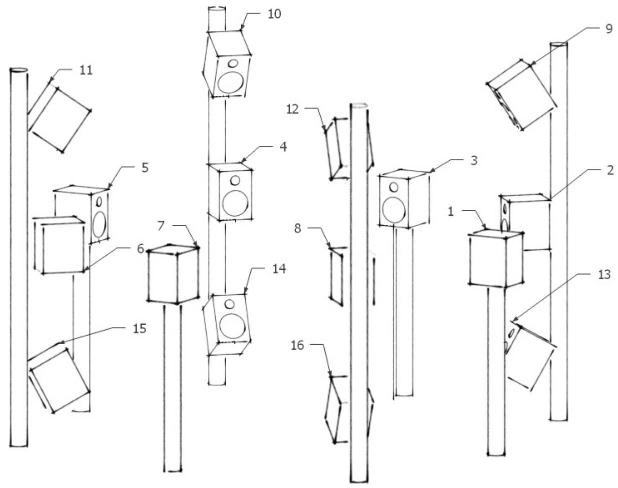

Figure 1: The evaluated setup contains 16 loudspeakers. Eight loudspeakers are arranged on a circle in the middle, four loudspeakers are positioned above and four at the bottom.

Ambisonics and Mode Matching

The Ambisonics signal representation can be seen as an audio format that represents the sound field instead of the individual loudspeaker signals [2–4]. The Ambisonics representation is therefore independent of the loudspeaker setup which is used for playback of the audio content. Thus, the Ambisonics format provides a high flexibility for the playback in different environments and is well suited as transport format [3]. It may be used for 3D loudspeaker setups as shown in Figure 1 [2]. The mode matching approach is a decoding method for Ambisonics signals to obtain the loudspeaker signals needed [4]. This method requires a mathematically regular loudspeaker setup to obtain optimum results. In contrast, the setup in this contribution is irregular and leads to problems in decoder design [5]. A solution of this problem is described in the next section.

Robust 3D Panning Functions

The *robust panning* as introduced by Poletti for 2D loudspeaker setups [6] optimises the sound field for a small listening region around the sweet spot instead of only a single point. We extended the robust panning approach to 3D loudspeaker setups. Following an optimisation process, for each loudspeaker the desired panning function is evaluated. From these panning functions an Ambisonics decoding matrix can be computed. With the robust panning approach the localisation of virtual sources can be improved compared to the mode matching approach [7]. Figure 2 compares the resulting panning functions for loudspeaker 2 from Figure 1. Only robust panning relates clearly to the addressed loudspeaker.

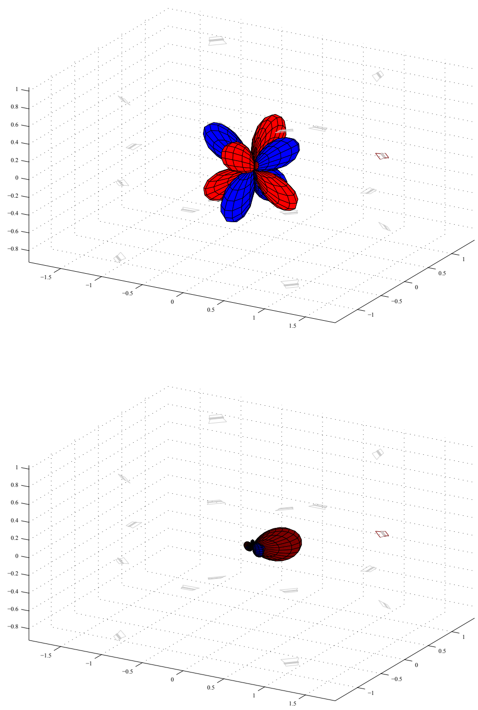

Figure 2: Panning functions obtained from the decoding matrix using mode matching (top) and 3D robust panning (bottom) for loudspeaker 2.

Listening Test

For the evaluation of the localisation of a single source, we compare a virtual source against a real source as a reference in a listening test [8]. For the real source we use a loudspeaker at the desired position. The compared rendering methods are VBAP, Ambisonics mode matching decoding and Ambisonics decoding using the newly developed 3D robust panning approach. For mode matching and robust panning, for each tested position and each tested input signal, an Ambisonics signal of third order is generated. This synthetic Ambisonics signal is then decoded using the corresponding decoding matrices. The test signals used are broadband pink noise and a male speech signal. The tested positions are placed in the frontal region with elevation angles of 14 and 27 degrees. The loudspeaker setup is the one as shown in Figure 1.

The listening test was conducted in an acoustic room with a mean reverberation time of approximately 0.2 s. Nine people participated in the listening test. The test subjects were asked to grade the spatial rendering performance of all playback methods compared to the reference. A single grade value had to be found to represent the localisation of the virtual source and timbre alterations.

Figure 3 shows the listening test results. Both VBAP and the newly proposed robust panning are graded significantly better than the mode matching Ambisonics decoding. In general, VBAP and robust panning show similar grades, where the confidence intervals are greater for VBAP. Compared to VBAP, the robust panning Ambisonics decoding has the advantage that not only three loudspeakers are used to render the virtual source. In VBAP single loudspeakers may be dominant if the virtual source position is close to one of the physical positions of the loudspeakers. In summary, the newly proposed 3D robust panning Ambisonics decoding can produce a spatial rendering quality similar to the one VBAP can produce. The robust panning approach requires only a soundfield description while VBAP requires a parametric description of the virtual sources to be rendered.

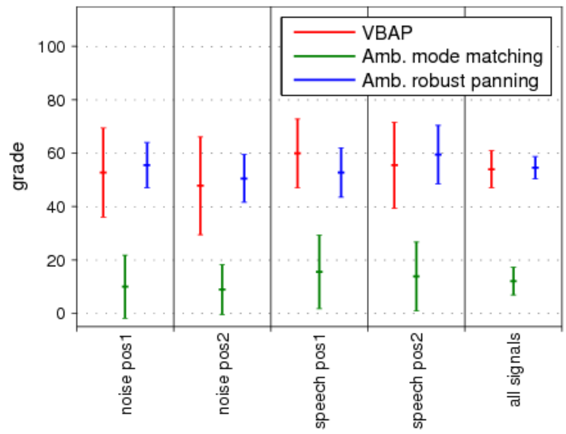

Figure 3: Listening test results as grades on a scale from 0 to 100 where 100 corresponds to excellent quality. Mean values and 95% confidence intervals are shown for the considered playback methods.

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