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Ambisonics

A Practical 3D Audio Theory for Recording, Studio Production, Sound Reinforcement, and Virtual Reality

Springer Open

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Preface

The intention of this textbook is to provide a concise explanation of fundamentals and background of the surround sound recording and playback technology Ambisonics.

Despite the Ambisonic technology has been practiced in the academic world for quite some time, it is happening now that the recent ITU,[1] MPEG-H,[2] and ETSI[3] standards firmly fix it into the production and media broadcasting world.

What is more, Internet giants Google/YouTube recently recommended to use tools that have been well adopted from what the academic world is currently using.[4,5]

Last but most importantly, the boost given to the Ambisonic technology by recent advancements has been in usability: Ways to obtain safe Ambisonic decoders,[6,7] the availability of higher-order Ambisonic main microphone arrays (Eigenmike,[8] Zylia[9]) and their filter-design theory, and above all: the usability increased by plugins integrating higher-order Ambisonic production in digital audio workstations or mixers.[7,10,11,12,13,14,15] And this progress was a great motivation to write a book about the basics.

[1] https://www.itu.int/rec/R-REC-BS.2076/en.

[2] https://www.iso.org/standard/69561.html.

[3] https://www.techstreet.com/standards/etsi-ts-103-491?product_id=1987449.

[4] https://support.google.com/jump/answer/6399746?hl=en.

[5] https://developers.google.com/vr/concepts/spatial-audio.

[6] https://bitbucket.org/ambidecodertoolbox/adt.git.

[7] https://plugins.iem.at/.

[8] https://mhacoustics.com/products.

[9] https://www.zylia.co.

[10] http://www.matthiaskronlachner.com/?p=2015.

[11] http://www.blueripplesound.com/product-listings/pro-audio.

[12] https://b-com.com/en/bcom-spatial-audio-toolbox-render-plugins.

[13] https://harpex.net/.

[14] http://forumnet.ircam.fr/product/panoramix-en/.

[15] http://research.spa.aalto.fi/projects/sparta_vsts/.

The book is dedicated to provide a deeper understanding of Ambisonic technologies, especially for but not limited to readers who are scientists, audio-system engineers, and audio recording engineers. As, from time to time, the underlying maths would get too long for practical readability, the book comes with a comprehensive appendix with the beautiful mathematical details.

For a common understanding, the introductory section spans a perspective on Ambisonics from its origins in coincident recordings from the 1930s, to the Ambisonic concepts from the 1970s, and to classical ways of applying Ambisonics in first-order coincident sound scene recording and reproduction that have been practiced from the 1980s on.

In its main contents, this book intends to provide all psychoacoustical, signal processing, acoustical, and mathematical knowledge needed to understand the inner workings of modern processing utilities, special equipment for recording, manipulation, and reproduction in the higher-order Ambisonic format. As advanced outcomes, the aim of the book is to explain higher-order Ambisonic decoding, 3D audio effects, and higher-order Ambisonic recording with microphones or main microphone arrays. Those techniques are shown to be suitable to supply audience areas ranging from studio-sized to hundreds of listeners, or headphone-based playback, regardless whether it is live, interactive, or studio-produced 3D audio material.

The book comes with various practical examples based on free software tools and open scientific data for reproducible research.

Our Ambisonic events experience: In the past years, we have contributed to organizing Symposia on Ambisonics (Ambisonics Symposium 2009 in Graz, 2010 in Paris, 2011 in Lexington, 2012 in York, 2014 in Berlin), demonstrated and brought the technology to various winter/summer schools and conferences (EAA Winter School Merano 2013, EAA Symposium Berlin 2014, workshops and Ambisonic music repertory demonstration at Darmstädter Ferienkurse für Neue Musik in 2014, ICAD workshop in Graz 2015, ICSA workshop 2015 in Graz with PURE Ambisonics night, summer school at ICSA 2017 in Graz, a course at Kraków film music festival 2015, mAmbA demo facility DAGA in Aachen 2016, Al Di Meola's live 3D audio concert hosted in Graz in June 2016, and AES Convention Milano 2018.

In 2017 (ICSA Graz) and 2018 (TMT Cologne), we initiated and organized *Europe's First* and *Second Student 3D Audio Production Competition* together with Markus Zaunschirm and Daniel Rudrich.

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Outline

First-order Ambisonics is nowadays strongly revived by internet technology supported by Google/YouTube, Facebook 360°, 360° audio and video recording and rendering, as well as VR in games. This renaissance lies in its benefits of (i) its compact main microphone arrays capturing the entire surrounding sound scene in only four audio channels (e.g., Zoom H3-VR, Oktava A-Format Microphone, Røde NT-SF1, Sennheiser AMBEO VR Mic.), and (ii) it easily permits rotation of the sound scene, allowing to render surround audio scenes, e.g., on head-tracked headphones, head-mounted AR/VR sets, or mobile devices, as described in Chap. 1.

Auditory events and vector-base panning: Chapter 2 of this book is dedicated to conveying a comprehensive understanding of the localization impressions in multi-loudspeaker playback and its models, followed by Chap. 3 that outlines the essentials of practical vector panning models and their extensions by downmix from imaginary loudspeakers, which are both fundamental to contemporary Ambisonics.

Harmonic functions, Ambisonic encoding and decoding: Based on the ideals of accurate localization with panning-invariant loudness and perceived width, Chap. 4 provides a profound mathematical derivation of higher-order Ambisonic panning functions in 2D and 3D in terms of angular harmonics. These idealized functions can be maximized in their directional focus (max-$\boldsymbol{r}_\mathrm{E}$) and they are strictly limited in their directional resolution. This resolution limit entails perfectly well-defined constraints on loudspeaker layouts that make us reach ideal measures for accurate localization as well as panning-invariant loudness and width. And what is highly relevant for practical decoding: All-Round Ambisonic decoding to loudspeakers and TAC/MagLS decoders for headphones are explained in Chap. 4.

The Ambisonic signal processing chain and effects are described in Chap. 5. It illustrates the signal flow from source encoding through Ambisonic bus to decoding and where input-specific or general insert and auxiliary Ambisonic effects are located. In particular, the chapter describes the working principles behind frequency-independent manipulation effects that are either mirroring/rotating/re-mapping, warping, or directionally weighting, or such effects that are frequency-dependent. Frequency-dependent effects can introduce widening, depth or diffuseness, convolution reverb, or feedback-delay-network (FDN)-based diffuse

reverberation. Directional resolution enhancements are outlined in terms of SDM/SIRR pre-processing of recorded reverberation and in terms of available tools such as HARPEX, DirAC, and COMPASS for recorded signals.

Compact higher-order Ambisonic microphones rely on the solutions of the Helmholtz equation, and their processing uses a frequency-independent decomposition of the spherical array signals into spherical harmonics and the frequency-dependent radial-focusing filtering associated with each spherical harmonic order, which yield the Ambisonic signals. The critical part is to handle the properties of radial-focusing filters in the processing of higher-order Ambisonic microphone arrays (e.g., the Eigenmike). To keep the noise level and the sidelobes in the recordings low and a balanced frequency response, a careful way for radial filter design is outlined in Chap. 6.

Compact higher-order loudspeaker arrays oppose the otherwise inwards-oriented Ambisonic surround playback, as described in Chap. 7. This outlooking last chapter discusses IKO and loudspeaker cubes as compact spherical loudspeaker arrays with Ambisonically controlled radiation patterns. In natural environments with acoustic reflections, such directivity-controlled arrays have their own sound-projecting and distance-changing effects, and they can be used to simulate sources of specific directivity patterns.

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