3D microphone arrays

A 3D recording comparison by **DR HYUNKOOK LEE**, director of the Applied Psychoacoustics Lab (APL), University of Huddersfield

/ Dr Hyunkook Lee

Immersive audio is one of the hottest topics for research and development in the audio industry right now. The exact definition of 'immersion' in audio is still in debate among researchers and engineers, but the term immersive audio in home/cinema entertainment usually refers to three-dimensional (3D) audio that provides the listener with the sense of height of sound as well as the width and depth, overcoming the limitations of conventional 2-channel stereo and 5.1 surround systems. In the context of audio for virtual/augmented reality, immersive audio technology allows you to hear sound from all directions in binaural headphone reproduction, which dynamically changes according to head rotation (so-called 360° audio).

Immersive audio is not 'the next big thing' anymore, but it is already becoming a new standard. Dolby Atmos, which allows a flexible panning of audio objects in a 3D auditory space, has become a standard cinema audio format for Hollywood films. Universal Music Group is remixing classic pop/rock/jazz albums in Dolby Atmos, and it is believed that they will start producing new albums in that format in the near future. High-resolution classical music albums are being produced in Dolby Atmos and Auro-3D formats by several high-resolution record labels. Immersive audio content can now be efficiently delivered to consumers' TV, soundbar or mobile devices with a new 3D audio codec MPEG-H. Amazon Music HD and Tidal are starting a streaming service of Sony's new 360 Reality Audio format which uses MPEG-H.

With these technological advances allowing home users to access 3D audio content more easily, I believe that the majority of audio content will be produced in an immersive format in the near future — and naturally sound engineers need to learn/develop new recording and mixing techniques. In the context of 3D acoustic recording, the surround and height channels can significantly help enhance the sense of being enveloped by sound and the naturalness or realism of the reproduced sound, and microphone technique plays a key role to achieve this aim.

Aural database compares 3D mic arrays

Over the recent years, several 3D main microphone arrays have been proposed by researchers and sound engineers. But still there is no concrete understanding about what kind of differences we can perceive among different techniques and how we can evaluate the quality of a 3D acoustic recording. And yet in professional recording sessions it is very

/ **Performers were captured by all 3D arrays simultaneously**

difficult to spend enough time on comparing many different techniques. This motivated me towards creating an open-access database of 3D music recordings and impulse responses made simultaneously with various different microphone array systems. This kind of resource would be found useful for the purposes of recording education, spatial audio research and critical ear training. The database is named '3D-MARCo' (3D Microphone Array Recording Comparison), and it is now available for free download from www.hud.ac.uk/apl/resources.

The recording sessions took place at the St. Paul's concert hall within the University of Huddersfield over three days (3-5 June) this year. The St. Paul's hall is a church-converted concert venue with a high ceiling, and the average reverb time is 2.1 seconds. Members of the Applied Psychoacoustics Lab (APL) within the University assisted on the session.

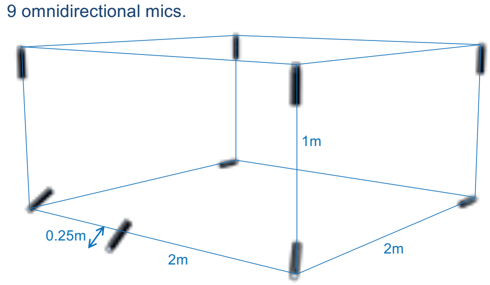
71 microphones — seven 3D arrays

We set up a total of 71 microphones to configure 7 different 3D microphone array systems (PCMA-3D, OCT-3D, 2L Cube (*Resolution* V6.4), Decca Cuboid, Hamasaki Square+Height, 32-channel spherical mic array (Eigenmike EM32) and first-order Ambisonics (Sennheiser Ambeo VR — reviewed *Resolution* V17.1). Additionally, microphones for the NHK 22.2 format (side and side height, overhead (so-called the Voice of God channel), floor) as well as the ORTF stereo pair, KU100 dummy head and spot microphones for individual instruments were also used.

You can find detailed theoretical information

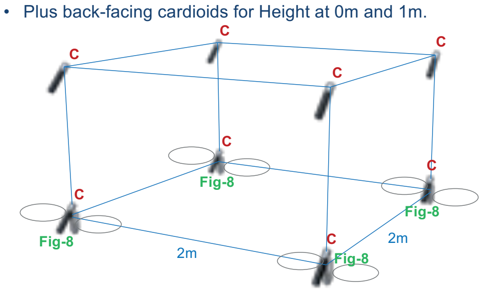
Decca Cuboid

- A modified Decca Tree augmented with rear and height mics.
- 9 omnidirectional mics.



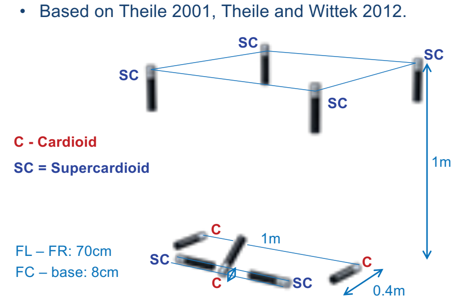
Hamasaki Square + Height

- Hamasaki Square (4 side-facing Fig-8s in a 2m x 2m square)
- Plus back-facing cardioids for Height at 0m and 1m.



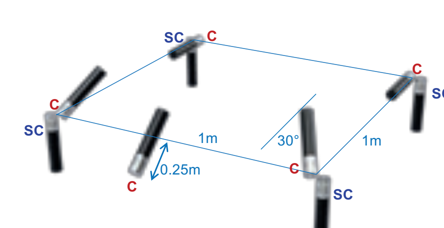
OCT-3D

- Based on Theile 2001, Theile and Wittek 2012.



PCMA-3D

- Based on Lee 2011, Lee and Gribben 2014.
- Horizontally spaced, vertically coincident.



/ **DPA Microphones supplied 45 extra mics**

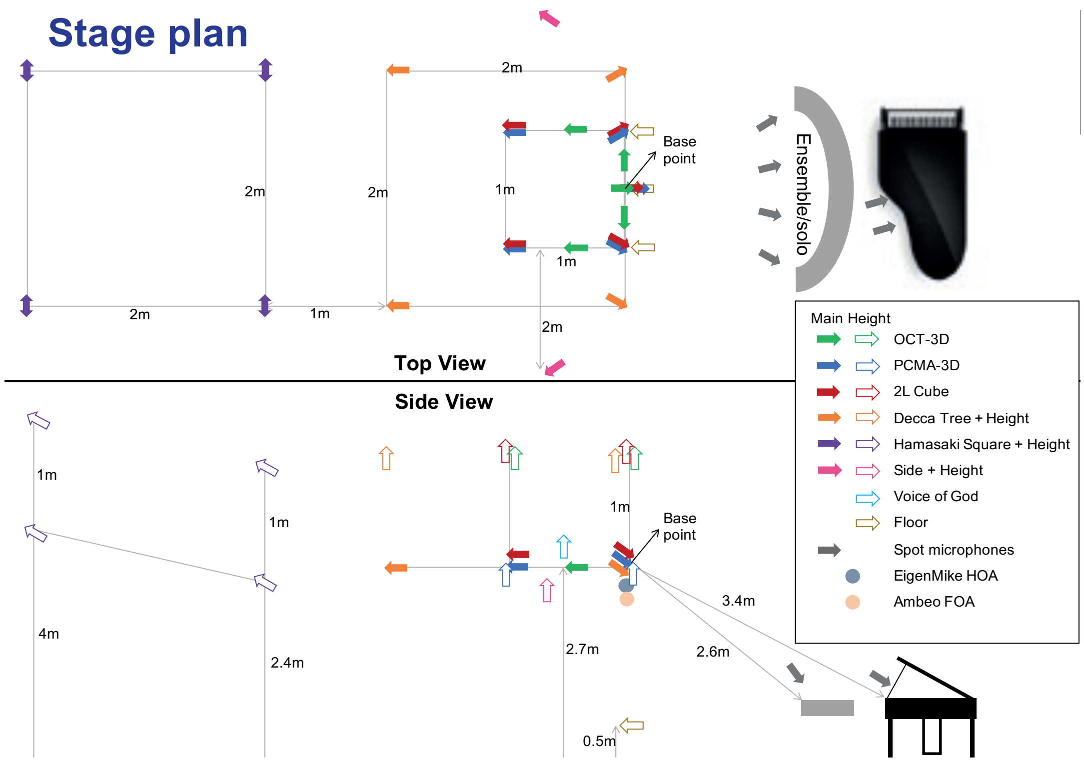
/ **The multi-capsule Eigen mic (ball-head) just above a Sennheiser Ambeo VR**

about all of the microphone techniques in the white paper from the download link above. Additionally, presentation slides for my recent tutorial session on this topic at the 147th AES convention can be found from *https://doi.org/10.5281/zenodo.3516141*. But to briefly summarise the main arrays used here, the OCT-3D is a vertical extension of a 5-channel array OCT-Surround, developed by Gunther Theile and Helmut Wittek [of Schoeps], using 4-supercardioid microphones facing directly upwards and placed 1m directly above the main layer. The 2L-Cube is a technique developed by Morten Lindberg of the 2L record label and it employs 9-omni microphones arranged in a 1m x 1m x 1m cube structure. The PCMA-3D is a horizontally spaced, vertically coincident array, developed by myself based on some of my previous psychoacoustic experimental results. It employs 5-cardioid microphones for the main layer and 4-upward-facing supercardioid microphones for the height layer in a 1m x 1m square. The Decca Cuboid is an improvisation of the famous Decca Tree, which adds two surround and four height microphones, all of which are omnis. The Eigenmike EM32 is a small spherical array that can produce a highly directional beamforming and higher-order Ambisonic signals. The Hamasaki Square is a popular 4-channel ambience capture technique using 4-figure-of-eight microphones, developed by Kimio Hamasaki, and it provides nicely de-correlated signals useful for providing listener envelopment. The array was augmented by 4 rear-facing cardioids for the height layer at 0m and 1m above it.

Sound sources recorded were various types of musical performances (String quartet, Trio, Organ, Piano solo, A Cappella, single sources at 13 different positions). They were captured with all of the microphones simultaneously. Since the main purpose of the project was to investigate spatial differences of the microphone arrays, it was crucial to use high-quality microphones with a flat frequency response from the same manufacturer, to minimise tonal differences, although omni-directional microphones would inevitably provide a deeper low-end than directional microphones. For this purpose, DPA Microphones kindly sponsored this project with 45 microphones (4006 omnis, 4011 cardioids and 4018 supercardioids), which were used for all of the discrete microphone arrays, together with an additional 15 DPA capsules which the University already owned.

All of the microphone signals apart from the

/ **When there are more mics than organ pipes...**



/ **Figure 1. Positioning of performers and mic arrays**

Eigenmike were amplified equally using the AD8DP preamps installed in two Horus interfaces provided by Merging Technologies. The recordings were made on the Reaper DAW at 24bit 96kHz, apart from the Eigenmike limited to 24bit 48kHz. In addition, room impulse responses were captured by all of the microphones at 13 source positions, with 15° intervals covering the 180° span using Genelec 8331A loudspeakers. This could be used for creating virtual ensembles by convolving them with dry sound sources, which might be useful for spatial audio experiment and education.

Figure 1 illustrates the physical setup for the recording session. All of the microphones for the 9-channel arrays OCT-3D, PCMA-3D and 2L-Cube were mounted on a Grade Design SpaceBar system extended vertically with custom-made poles and joiners, forming a 1m cube structure. Microphones for the Decca Cuboid, which requires 2m x 2m x 1m, were placed on separate stands, apart from the centre microphone that was shared with the 2L-Cube. The main layer of the PCMA-3D was placed 2.6m high from the floor. Those of the 2L-Cube and OCT-3D were 5 to 10cm above and below that of the PCMA-3D, respectively. The front pair of the Hamasaki Square was placed 3.1m behind the main array base point.

The main arrays were raised at 2.6m from the floor and the height layer microphones were placed directly above the main layer microphones. In a practical recording situation, the recording engineer would find different optimal positions for different arrays based on their polar patterns and configurations. But in this shootout session all of the arrays apart from the Hamasaki Square shared the same base point since my main interest was to elicit perceived differences among the arrays at the same acoustic reference point.

The next step for me is to conduct a formal subjective experiment to elicit perceived differences among the microphone arrays. Results from this experiment will become the basis to construct a set of attribute scales that can be used for evaluating the perceived qualities of 3D acoustic recordings. From initial informal listening sessions, we observed differences such as stability in vertical and horizontal localisation, apparent source width, perceived depth, listener envelopment and tonal clarity.

Start your own immersive journey!

However, this certainly varied depending on the type of sound source as well as the location of the source. Also, no single array was preferred for all types of sound sources. Ultimately, the purpose of the 3D-MARCo database is to help audio professionals understand the pros and cons of different techniques for different types of content. In the end, all of these arrays tested here are good references to start with but not the only options for 3D recording. By understanding the design principle of each array, you would be able to adapt/customise the array yourself or even create your own based on the artistic and technical aims for your recording. I hope that the 3D-MARCo would inspire you to start your own journey of immersive recording.

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