3D soundfield analysis using spherical harmonic decomposition by circular arrays

1 Motivation

• 3D wavefield analysis is essential in understanding the complete behavior of signals in space and time. There are numerous applications that would benefit from this work, such as directional 3D beamforming (used in teleconferencing), direction of arrival estimation (direct recordings for 5.1, 7.1 surround sound systems), directional noise detection and cancellation, and many more.

• Spherical harmonic decomposition of soundfields is a useful tool in studying, measuring and reconstructing signals in 3D space. It enables us to decompose the wavefield into a basis set of coefficients that essentially represent the entire field in the 3D region of interest. These coefficients can then be used to perform different functions depending on the application.

• Whilst spherical microphone arrays [1, 2, 3, 4] have been shown to be a natural choice for spherical harmonic decomposition, there are number of limitations and constraints which restrict their usefulness. Specifically, the sensors need to meet a strict orthogonality conditions resulting in a limited flexibility of array geometry, and thus suffer from numerical ill conditioning at some frequencies.

• We use a set of parallel circular arrays of sensors to decompose a soundfield into spherical harmonic components.

• Underlying structure of the wave propagation together with the properties of the associated Legendre functions and the spherical Bessel functions are used to develop a systematic approach to place circular arrays to construct a hybrid array.

• Sensor positions of spherical arrays need to meet a strict orthogonality conditions resulting in a limited flexibility of array geometry, and they suffer from numerical ill conditioning at some frequencies.

2 Spherical harmonic analysis of 3D soundfields

Consider a point \((r, \theta, \phi)\) within a source free region \(\Omega\). A soundfield at a point \((r, \theta, \phi)\) in \(\Omega\) can be expressed as

$$S(r, \theta, \phi) = \sum_{n=0}^{\infty} \sum_{m=-n}^{n} a_{n,m}(r) \sin(\theta) P_{n,m}(\cos(\theta))$$

where \(k = 2\pi f / c\), \(f\) frequency, \(c\) speed of sound, \(a_{n,m}(r)\) are the spherical harmonic coefficients of the soundfield, \(P_{n,m}\) are the spherical Bessel functions, \(\sin(\theta) P_{n,m}(\cos(\theta))\) are the normalized associated Legendre functions, \(\cos(\theta)\) are the normalized spherical harmonics.

2.1 Insight into harmonic structure

1. Radius and Frequency dependency

2. Combination of Circles

3 Results

3.1 Advantages over spherical Arrays

1. Accuracy

• Smaller circles to decompose lower order coefficients, bigger circles to decompose higher order coefficients

• Odd coefficients separated from even through odd and even placement of circles

2. Flexibility

• Placement of sensors

• Ease of practical implementation

3. Robustness

• Addresses numerical stability

• A range of elevation angles for placement of circles with suitable Legendre values

• A number of circles with different radii to serve the whole frequency band

4 Conclusion

• Spherical harmonic decomposition is a useful tool to analyse 3D soundfields.

• Spherical arrays have inherent limitations that make them unsuitable for practical implementation. Circular microphone arrays and hybrid arrays need carefully designing based on underlying wavepropagation and theory.

• Circular arrays provide increased accuracy, flexibility and robustness for operation over a frequency octave.

• Combining circular arrays enables us to calculate odd and even harmonics independently, providing cleaner more accurate results

• Future research - 3D beamforming using circular arrays

References & Publications


