Beamforming with the Eigenmike

Author: Stefanie Brown  Student #: z3158237
Supervisor: Deep Sen  Assessor: Vijay Sivaraman

Introduction

The Eigenmike em32
This microphone array consists of 32 omnidirectional electret capsules arranged on the surface of a rigid sphere, at the positions corresponding to the centres of the faces of a truncated icosahedron (soccer ball). It was simulated in MATLAB for this thesis.

Beamforming
This is the technique of combining the outputs of a microphone array to form a beam. This isolates sounds arriving from the direction pointed to by the beam. Spherical Harmonic Beamforming is used in this thesis.

Why would you want to?
Highly directional microphones exist, but they are bulky and require manual orientation. A spherical array is small and discreet, while the beam can be oriented in any direction without moving the microphone.

Spherical Coordinates
The coordinate system used herein is described by the diagram (right), where \( \theta \) represents inclination from the positive z-axis and \( \phi \) is the azimuth from the positive x-axis.

Methodology

Spherical Harmonics (SH)
These functions constitute part of the solution to the wave equation in spherical coordinates. They represent spatial filters and are the basis functions from which any desired beampattern may be created. The P function is the Associated Legendre Function.

\[
Y_n^m(\theta, \phi) = \frac{2n+1}{4\pi} \frac{\sin m\phi}{n! (n+m)!} P_n^m(\cos \theta) e^{im\phi}
\]

where \( n \) is the order, and \( m \) is the degree, \( m = \{-n \ldots n\} \)

Spherical Harmonic Coefficients
A soundfield can be described by a linear combination of SHs at all frequencies present.

\[
P(kr, \theta, \phi, f) = \sum_{n=0}^{\infty} \sum_{m=-n}^{n} A_n^m(f) Y_n^m(\theta, \phi)
\]

\[
\begin{bmatrix}
P_x(f) \\ P_y(f) \\ P_z(f)
\end{bmatrix} = \begin{bmatrix}
j_0(kr) Y_0^0(\theta, \phi) & \ldots & j_n(kr) Y_n^0(\theta, \phi)
\end{bmatrix} A_n^0
\]

The em32 is capable of extracting SHs up to 4th order. For higher orders, the Bessel functions tend to zero, so ignoring higher orders is acceptable.

The SH coefficients represent the signal level at that frequency and location. They can be extracted by performing an approximate matrix inversion (B is not square) and multiplication.

\[
[P(f)] = [B][A_n^m] \quad [A_n^m] = [B]^{-1}[P(f)]
\]

Conclusions
Using the technique of Spherical Harmonic beamforming, I successfully created a beamformer capable of creating optimum cardioid-family beampatterns up to 4th order, as well as a range of functions to plot the resulting beams in 3D.