Experimental Evaluation Of The Performances Of A New Pressure-Velocity 3D Probe Based On The Ambisonics Theory

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Goals

- Explanation of the Ambisonics technology, as currently employed in room acoustics
- Brahma: the first underwater 4-channels digital sound recorder
- A tetrahedral hydrophone array for Brahma
- Sound source localization from Ambisonics (B-format) recordings
- Graphical mapping of boat trajectory
Ambisonics technology

• Ambisonics was invented in the seventies by Michael Gerzon (UK)
• It was initially a method for recording a 4-channel stream, which later was played back inside a special loudspeaker rig
• It is based on the pressure-velocity decomposition of the sound field at a point
• It makes it possible to capture the complete three-dimensional sound field, and to reproduce it quite faithfully
Ambisonics recording and playback

Reproduction occurs over an array of 8-24 loudspeakers, through an Ambisonics decoder.
Ambisonics Technology

Recording

Processing

Decoding

Speaker-feeds

Playback

Encoding

B-Format
The Soundfield microphone

- This microphone is equipped with 4 subcardioid capsules, placed on the faces of a tetrahedron.
- The signal are analogically processed in its own special control box, which derives 4 “B-format” signals.
- These signals are:
  - $W$: omnidirectional (sound pressure)
  - $X,Y,Z$: the three figure-of-eight microphones aligned with the ISO cartesian reference system – these signals are the cartesian components of the “particle velocity” vector.
Other tetrahedral microphones

- Trinnov, DPA, CoreSound, Brahma are other microphone systems which record natively the A-format signals, which later are digitally converted to B-format
The B-format components

- Physically, $W$ is a signal proportional to the pressure, $XYZ$ are signals proportional to the three Cartesian components of the particle velocity.

- When a sound wave impinges over the microphone from the “negative” direction of the x-axis, the signal on the X output will have polarity reversed with respect to the $W$ signal.
A-format to B-format

- The A-format signals are the “raw” signals coming from the 4 capsules, located at 4 of the 8 vertexes of a cube, typically at locations FLU-FRD-BLD-BRU.
A-format to B-format

- The A-format signals are converted to the B-format signals by matrixing:
  
  \[ W' = FLU + FRD + BLD + BRU \]
  
  \[ X' = FLU + FRD - BLD - BRU \]
  
  \[ Y' = FLU - FRD + BLD - BRU \]
  
  \[ Z' = FLU - FRD - BLD + BRU \]
  
- and then applying proper filtering:
  
  \[ F_W = \frac{1 + j\omega r / c - \frac{1}{3} (\omega r / c)^2}{1 + \frac{1}{3} j\omega r / c} \]
  
  \[ F_{XYZ} = \sqrt{6} \frac{1 + \frac{1}{3} j\omega r / c - \frac{1}{3} (\omega r / c)^2}{1 + \frac{1}{3} j\omega r / c} \]
  
  *r = distance of each capsule from the center of the tetrahedron in m*
  
  *\omega = angular frequency in rad/s (\omega = 2\pi f)*
  
  *c = speed of sound in m/s*
Recording

Directional components:
- velocity

Omnidirectional component:
- pressure

Soundfield Microphone

B-FORMAT

Polar Diagram
Encoding (synthetic B-format)

<table>
<thead>
<tr>
<th>0</th>
<th>W</th>
<th>$=0.707 \times s(t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
<td>$=\cos(A)\cos(E) \times s(t)$</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>$=\sin(A)\cos(E) \times s(t)$</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>$=\sin(E) \times s(t)$</td>
</tr>
</tbody>
</table>

$s(t) = \frac{1}{\sqrt{X^2 + Y^2 + Z^2}}$
Processing

**Recording**

**Encoding**

**Processing**

**Decoding and Playback**

\[ w' = w \]
\[ x' = x \cdot \cos(R) - y \cdot \sin(R) \]
\[ y' = x \cdot \sin(R) + y \cdot \cos(R) \]
\[ z' = z \]

**Rotation**

\[ w' = w \]
\[ x' = x \]
\[ y' = y \cdot \cos(T) - z \cdot \sin(T) \]
\[ z' = y \cdot \sin(T) + z \cdot \cos(T) \]

**Tilt**

\[ w' = w \]
\[ x' = x \cdot \cos(T) - z \cdot \sin(T) \]
\[ y' = y \]
\[ z' = x \cdot \sin(T) + z \cdot \cos(T) \]

**Tumble**
Each speaker feed is simply a weighted sum of the 4 B-format signals. The weighting coefficients are computed by the cosines of the angles between the loudspeaker and the three Cartesian axes.

\[ F_i = \frac{1}{2} \left[ G_1 \cdot W + G_2 \cdot (X \cdot \cos(\alpha) + Y \cdot \cos(\beta) + Z \cdot \cos(\gamma)) \right] \]
Software for Ambisonics decoding

- Audiomulch VST host
- Gerzonic bPlayer
- Gerzonic Emigrator
Software for Ambisonics processing

Visual Virtual Microphone by David McGriffy (freeware)
Rooms for Ambisonics playback

ASK (UNIPR) – Reggio Emilia

University of Ferrara

University of Bologna
Rooms for Ambisonics playback

University of Parma (Casa della Musica)
BRAHMA: 4-channels recorder

• A Zoom H2 digital sound recorder is modified in India, allowing 4 independent inputs with phantom power supply
BRAHMA: 4-channels recorder

- The standard microphone system is usually a terahedrical probe equipped with 4 cardioid electrect microphones
BRAHMA: 4-channels recorder

- However the recorder is equipped also with a split-out cable, allowing for the connection of other transducers, including microphones, accelerometers and hydrophones.
Hydrophones for Brahma

- Brahma provides phantom power (5V) for transducers equipped with integral electronics. Hence the ideal hydrophone is the Acquarian Audio H2A:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sensitivity</strong></td>
<td>-180dB re: 1V/μPa (+/-4dB 20Hz-4.5KHz)</td>
</tr>
<tr>
<td><strong>Frequency range</strong></td>
<td>&lt;10 Hz to &gt;100KHz (approximate sensitivity @100KHz = -220dB re: 1V/μPa)</td>
</tr>
<tr>
<td><strong>Polar Response</strong></td>
<td>Omnidirectional (horizontal)</td>
</tr>
<tr>
<td><strong>Operating depth</strong></td>
<td>&lt;80 meters</td>
</tr>
<tr>
<td><strong>Output impedance</strong></td>
<td>1 KΩ (typical)</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>0.6 mA (typical)</td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td>(cable and output plug excluded)</td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
<td>25mm x 46mm</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>105 grams</td>
</tr>
</tbody>
</table>

Aquarian Audio Products
A division of AFAB Enterprises
1004 Commercial Ave. #225 Anacortes, WA 98221 USA
(360) 299-0372 [www.AquarianAudio.com](http://www.AquarianAudio.com)
Hydrophones for Brahma

- A tetrahedrical assembly can be built for underwater Ambisonics recording:

A regular tetrahedron is obtained placing the 4 hydrophones at 4 of the 8 vertexes of a cube measuring 80mm x 80mm x 80mm
Underwater probe for Brahma

• For underwater recordings, a special setup of 4 screw-mounted hydrophones is available:
Underwater case for Brahma

- Due to the small size (like a cigarette packet) it is easy to insert the Brahma inside a waterproof cylindrical container, sealed with O-rings.
- An external lead-acid battery can be included for continuous operation up to one week (in level-activated recording mode).
Soundfish : 4-channels recorder

• The probe can be mounted on a weighted base, allowing for underwater placement of the recorded, inside a waterproof case. However, the cables are long enough (15m) also for keeping the recorder on the boat.
Soundfish: 4-channels underwater recorder

- The system is aligned vertically by means of a bubble scope, and horizontally by means of a magnetic compass:
Soundfish: 4-channels underwater recorder

- Once placed on the sea bed, the system is usually well accepted (and ignored) by the marine life:
Brahmavolver: the processing software

- Brahma records A-format signals. They can be converted to standard B-format by means of the Brahmavolver program, running on Linux / Windows / Mac-OSX.
BRAHMA: technical specs

- Sampling rates: 44.1 kHz, 48 kHz, 96 kHz (2 ch. only)
- Recording format: 1 or 2 stereo WAV files on SD card
- Bit Resolution: 16 or 24 bits
- 3 fixed gain settings, with 20 dB steps (traceable)
- Memory usage: 1.9 Gbytes/h (@ 44.1 kHz, 24 bits, 4 ch.)
- Recording time: more than 16 hours (with 32 Gb SD card)
- Power Supply: 6 V DC, 200 mA max
- Automatic recording when programmable threshold is exceeded
- The SD card can be read and erased through the USB port
Source localization from B-format signals

- At every instant, the source position is known in spherical coordinates by analyzing the B-format signal.

\[ \alpha = \text{azimuth} \quad \theta = \text{elevation} \]
Trajectory from multiple recording buoys

- Employing several buoys, the complete trajectory can be triangulated.
Characterization of the probe

- Impulse response measurements inside a large pool

\[ d = 1 \ldots D \]

source positions

\[ m = 1 \ldots M \]

hydrophones
Characterization of the probe

• Polar patterns at two frequencies
First experiment: M.P.A. Miramare

- The Marine Protected Area of Miramare (Trieste, Italy)
First experiment: M.P.A. Miramare

• Noise measurements

A boat was moving around the probe
First experiment: M.P.A. Miramare

- Noise spectra (SAN and boat passage)

Note the difference between the sound pressure and particle velocity spectra
First experiment: M.P.A. Miramare

• Vectorial analysis of a boat passage

The B-format component magnitudes (left) and the corresponding Sound Intensity Cartesian components (right)
First experiment: M.P.A. Miramare

• Estimated boat trajectory
Internet resources

All the papers previously published by Angelo Farina can be downloaded from his personal web site:

www.angelofarina.it