THREE-DIMENSIONAL ACOUSTIC DISPLAYS IN A MUSEUM EMPLOYING WFS (WAVE FIELD SYNTHESIS) AND HOA (HIGH ORDER AMBISONICS)

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The “Casa del Suono”

- It was born thanks to the cooperation of University of Parma, Comune of Parma, and with funds (approximately 2 million Euros) provided by Casa della Musica, Italian Government and Cariparma Foundation.

- The institutional goal is to display the famous Patanè’s Collection of vintage grammophones and radios, made available by CNIT (National Italian Consortium for Telecommunications).

- It is also a research lab about electroacoustics, equipped with the latest technologies for sound recording and reproduction employing a large number of channels.
Topics

• Restoration of the S. Elisabetta church
• Exhibit of Patanè’s Collection
• Sound system for the exhibit
• The SONIC CHANDELLIER, an innovative planar WFS installation
• 30-seats listening room (linear WFS)
• The single-seat listening room (Binaural, Ambisonics, Ambiophonics)
The S. Elisabetta Church

A Baroque square church, with annexed rectangular chapel
The main room is characterized by a very tall dome, with a lot of light thanks to many windows; in the center of the dome the SONIC CHANDELLIER was installed.
The S. Elisabetta church

Before the restoration the building was in miserable conditions
The S. Elisabetta church

Advanced restoration techniques revamped the original beauty
However, these restoration and consolidation techniques caused the acoustical behaviour of the church to worsen significantly, raising the reverberation time of the empty room from 2.3 s to more than 4.0 s.
6 circular niches in glass and steel, located in the 6 chapels of the main church, contain the major part of the “pieces” being exposed
In the rear chapel, the two “surround” listening rooms are located
Patanè’s Collection

• The collection was donated to CNIT by don Giuseppe Patanè, a priest and a collector, who employed his entire, long life for searching, purchasing and repairing valuable pieces.

• The collections contains approximately 400 pieces, ranging from the first phonographs, to Galen radios and extends to domestic and military radios of 20’s, 30’s, 40’s up to the first years after WWII. All pieces have been carefully maintained and serviced, most of them are working as new....

• There are also some particularly rare pieces, such as a cryptographic “Enigma” machine, employed by the German army for transmitting encoded informations during WWII.
Patanè’s Collection

- Some samples from the collection
Patanè’s Collection

• Some samples from the collection

- RCA Radiola 26
  6 valvole - superferodina - 1925

- Ramazzotti tipo RD8
  8 valvole - 1927

- Stromberg-Carlson mod. 654 - A
  1929
Patanè’s Collection

- Some samples from the collection
Exhibit’s sound system

Touch screen

Speaker

Speakers
Exhibit’s sound system

Two vertical 13-speakers line-arrays are employed. A DSP unit focalizes the sound downwards, where absorptive “sound traps” are located, for avoiding to spread the sound all around the church.
DSP control of line arrays

QSC 8-channels amplifier + BASIS DSP controller / Cobranet interface
DSP control of line arrays
Niche n. 1 - PHONOGRAPHS AND GRAMMOPHONS
1897-1923
The Niches

Niche n. 2 - RADIO
1921-1926
Niche n. 3 - RADIO and GRAMMOPHONS
1926-1929
Niche n. 4 - RADIO
1930-1935
The Niches

Nicchia n. 5 - RADIO AND RADIONICHIKGOPHONS
1935-1954
The Niches

Nicchia n. 6 - RADIO, TURNTABLES, AMPLIFIERS, STEREO
1950 - 2007
The "Sonic Chandellier"

Absorption

500 Hz

1 kHz

2 kHz
Design and Construction
Design and Construction

Special 32 Ohm model by Ciare
Installation
Hardware (computer, converters, amplifiers)

- Computer Linux multiprocessor
- Interface PCI->MADI (RME)
- Interface MADI->ADAT (RME)
- 8 x converters ADAT 8ch. (Behringer)
- 8 x amplifiers 8ch. (QSC mod. 1608)
Hardware (computer, converters, amplifiers)

64 output channels
Software structure on Linux PC

Audio Application + WFS plug-in

“WFS Focus” Software (runtime controlled multichannel processor)

MIDI or OSC controller

External Audio

Audio Mono 1

Audio Mono 2

Audio Mono 1

MIDI or OSC

OSC

WFS GUI

OSC

Audio 64 ch (MADI bus)

OSC

to the feeding system...
Software

"WFS Focus" structure

IN
Src 1
Src 2
Src S

FIR 1
FIR 2
FIR S

... S x 64 Gain-Delay couples

FIR 1
FIR 2
... FIR64

Ch 1
Ch 2

OUT
Ch C

MIDI or OSC
Space control
Listening rooms
- La sala bianca ospita sino a 30 ascoltatori, ed è dotata di un sistema surround planare tipo WFS (192 altoparlanti)
30-seats room ("sala Bianca")

- 176 loudspeakers are incorporated in the perimetral walls, completely surrounding the audience at ear-height
The WFS technology

- Wave Field Synthesis is a playback technique which makes use of linear loudspeaker arrays which are used for creating wavefronts appearing to be radiated by a virtual source
- Concept: spatially sampling a wavefront
WFS applications

- WFS can generate point sources or planar sources, and even point sources which appear to be inside the room, in the middle of the audience area.
Tecnology WFS @ IRCAM, IRT
Synthesis of a virtual environment with WFS

- Recording
  - Orchestra
  - Soloist
  - Stereophonic mix
  - Wave field synthesiser (Convolution)
- Room response measurement
- Storage
FREE Software for WFS

- The Linux program Wonder makes it possible to generate WFS signals and to move in real-time the virtual source being synthesized.
Low-cost hardware for WFS

- The cheaper solution is based on a PC containing three MADI interfaces (64 ch. each), connected with a rack of low-cost converters (Behringer)

Nota:
- 3 MADI = 192 channels
- Disadvanze = 12 channels

176 channels +
\[ \times 4 = 180 \text{ channels} \]
Single-seat room ("sala Nera")

- This room is equipped with 26 loudspeakers
• The walls are made by plywood, gypsum boards and perforated panels with polyester fiber wool, providing good sound insulation and optimal control of reverberation.
• The sound absorbing treatment, here simulated employing the Ramsete program, provides a value of T20 of 0.40 s at 125 Hz and even lower at higher frequencies.
• Playback is made on 2 loudspeakers located at +/- 10°, being fed through a digital cross-talk cancellation system
Binaural (Dual Stereo Dipole)

**Pro:**
- 3D sound reproduction
- Cross-talk cancellation filters also equalize perfectly loudspeaker and microphones

**Contro:**
- Poor low frequencies
- Colouring outside the “sweet spot”

Schematics:

![Diagram of Binaural (Dual Stereo Dipole) with subwoofer and axes labeled X, Y, Z.](image)
Ambisonics Method

Recording

Processing

Playback

Encoding

Encoding

Decoding

Decoding

B-Format

Speaker-feeds
The Soundfield (TM) microphone provides 4 signals:
1 omnidirectional (pressure, W) and 3 figure-of-8 (velocity, X, Y, Z)
Soundfield microphone

Directional components:
- velocity

Omnidirectional component:
- pressure

B-FORMAT

Polar diagrams
<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>W</td>
<td>=0.707 *s(t)</td>
</tr>
<tr>
<td>1</td>
<td>X</td>
<td>=cos(A)cos(E) *s(t)</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td>=sin(A)cos(E) *s(t)</td>
</tr>
<tr>
<td></td>
<td>Z</td>
<td>=sin(E) *s(t)</td>
</tr>
</tbody>
</table>

\[ \sqrt{X^2 + Y^2 + Z^2} = 1 \]

\[ s(t) = \text{[sound wave]} \]
\[ w' = w \]
\[ x' = x \cdot \cos(R) - y \cdot \sin(R) \]
\[ y' = x \cdot \sin(R) + y \cdot \cos(R) \]
\[ z' = z \]

Rotation

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

Tilt

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

Tumble
Decoding

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

<table>
<thead>
<tr>
<th>Frequenza</th>
<th>( G_1 )</th>
<th>( G_2 )</th>
<th>( \Gamma = \frac{G_2}{G_1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;500Hz</td>
<td>( \sqrt{2} )</td>
<td>( \sqrt{2} )</td>
<td>1</td>
</tr>
<tr>
<td>&lt;500Hz</td>
<td>( 1 )</td>
<td>( \sqrt{3} )</td>
<td>( \sqrt{3} )</td>
</tr>
</tbody>
</table>

3D decoding

<table>
<thead>
<tr>
<th>Versione</th>
<th>Nome</th>
<th>Autore</th>
<th>( G_1 )</th>
<th>( G_2 )</th>
<th>( \Gamma = \frac{G_2}{G_1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>Sala da concerto, per tutte le frequenze</td>
<td>D.Malham</td>
<td>( \sqrt{8}/\sqrt{3N} )</td>
<td>( \sqrt{8}/\sqrt{3N} )</td>
<td>1</td>
</tr>
<tr>
<td>b)</td>
<td>Studio, alte frequenze</td>
<td>M.Gerzon</td>
<td>( \sqrt{8}/\sqrt{4N} )</td>
<td>( \sqrt{8}/\sqrt{2N} )</td>
<td>( \sqrt{2} )</td>
</tr>
<tr>
<td>c)</td>
<td>Studio, basse frequenze</td>
<td>M.Gerzon</td>
<td>( \sqrt{8}/\sqrt{6N} )</td>
<td>( \sqrt{2}/\sqrt{3N} )</td>
<td>2</td>
</tr>
<tr>
<td>d)</td>
<td>Studio, frequenze molto basse</td>
<td>J.M. Jot</td>
<td>( \sqrt{8}/\sqrt{2N^2} )</td>
<td>( \sqrt{2}/\sqrt{N^2} )</td>
<td>2</td>
</tr>
</tbody>
</table>

2D decoding

ker i-esim
High Order Ambisonics (HOA)

- As a complex time-domain waveform can be thought as the sum of a number of sinusoidal and cosinusoidal functions, so a complex spatial distribution around a given notional point can be expressed as the sum of a number of spherical harmonic functions.
- When the signals corresponding to spherical harmonics up to 3° order are summed with proper gains, one obtains a “virtual microphone” having a directivity pattern which can be very complex and highly directive.
Spherical Harmonics
3rd-order spherical microphone
Linux - Jack: AmbiDeco decoder by Fons Adriansen (open source, free)
Windows: VST plugins by Gerzonic, Dave Malham, Bruce Wiggins (freeware)
Software for Ambisonics processing

Windows: Visual Virtual Microphone by David McGriffy (freeware)
Low-cost hardware for HOA

- Again, a PC with MADI interface is employed
Locations of loudspeakers

- Horizontal Ambisonics octagon
- Ambisonics 3D cube
- Standard Stereo
- Frontal Stereo-Dipole
- Rear Stereo Dipole
- Upper Stereo Dipole
Psychoacoustics research

- Musical Food: sound quality analysis of Barilla - Mulino Bianco crackers and bread substitutes
Psychoacoustics research

- Listening tests with compilation of sound quality questionnaires
Psychoacoustics research

- Principal Component Analysis and correlation among physical and perceptual parameters
• Definizione contenuti espositivi e coordinamento: Alessandro Rigolli (per l'Istituzione Casa della Musica)
• Progettazione allestimento espositivo: Dario Costi e Simona Melli architetti
• Realizzazione allestimento espositivo:
  – Leonardo Laboratorio di Costruzione S.n.c. via G. Giusti, 4/a Parma
  – Gruppo Fallani S.r.l. via Pialoi, 100 Marcon (Ve)
  – Tecno-fer S.r.l. v.le Basetti, 14 Parma
• Progettazione e realizzazione componente acustica (LAE):
  – AIDA srl via G. Sicuri, 60/a Parma
  – Genesis via Benedetta, 83 Parma
  – Audiolink via Monte Prinzera, 17 Parma
• Sistemi informatici: IT City S.p.A. via Traversetolo, 36/a Parma
• Cablaggio:
  – Albacom.Amps Telecomunicazioni S.p.A.
  – Guglielmo srl via Livatino 9 Reggio Emilia
    Act Parma Srl via Lolio Guidotti 15/A Parma
Thanks to:

- The design and construction of these sound systems have been possible thanks to:

Laboratory of Acoustics and Elettroacoustics (LAE)

www.laegroup.org

Parma