Prominent Features of Binaural Hearing

- Localization
  Formation of positions of the auditory events (azimuth, elevation, distance, spatial extent), auditory room impression, immersion

- Suppression of
  the directional information coming from reflections (Precedence Effect, localization dominance, fusion), reverberation, coloration and noise

- Identification & segregation of
  auditory streams, e.g., concurrent talkers (Cocktail-Party Effect)

Generic Tasks of Sound Systems

1. Reproduction/Transmission
2. Augmentation/Enhancement
3. Simulation/Creation

An operational definition:

**Binaural Technology**

is a body of methods that involve acoustic input signals to both ears of the listener for achieving practical purposes, e.g., by recording, analyzing, synthesizing, processing, presenting and evaluating such signals.
Binaural Technology (I)

Measuring Head-Related Transfer Functions (HRTFs)
- Little electret microphones, inserted into the ear canals
- Measuring signals are, e.g.:
  - Noise, impulse trains or sinusoids
  - Anechoic chamber

A Set of Binaural Impulse Responses

Localization Errors with Non-optimum HRTFs

Representative HRTFs
Parametric Modelling of the External Ear

Binaural Technology (I)

Architecture for a Model of Binaural Hearing

Structure of the Model of Binaural Hearing
Potential Applications for Binaural Algorithms

Suitable for Short-Term Implementation

Source-Position Finders
- Tools for Architectural-Acoustics Evaluation (e.g., spatioacoustic meter, echo detector)
- Tools for Noise-Quality Evaluation (e.g., binaural loudness meter, binaural sensory-consonance meter)
- Tools for Fixing Binaural Recordings
- Cocktail-Party Processors (e.g., for signal-processing hearing aids or as a front end for speech recognizers)
- Adaptive-Pick-Up Devices for Hands-Free Telephones
- Microphone Sets for Acoustically Adverse Conditions (e.g., to reduce noise, reverb, and coloration)
- Tele-Surveillance Systems (e.g., automatic source identification and assessment)
- Tools for Psychoacoustic Research and Assessment
- 
- Blauert 1988

Binaural Technology at its Best

- provided that binaural signals are used
Binaural Synthesis of Sound Fields in Enclosures

- **Ray Tracing**
- **Mirror Imaging**
- **Binaural-Room-Simulation System**

- Coarse resolution: 48 planes
- Medium resolution: 126 planes
- Finest resolution: 238 planes

Checking for Perceptual Authenticity in Binaural Room Simulation

**Room-Acoustics & Sound-Systems Planning**

(1) **SOUND-SPECIFICATION PHASE**

In this phase, dummy-head recordings from real rooms and from prior computer simulations are used to come to an agreement with the client on the "sound" to be created in the new facility.

(2) **DESIGN PHASE**

During this phase, relatively simple computer models of the planned sound field are created, that can be modified with little effort. They allow for binaural listening at arbitrary positions in the sound field, thus enabling clients and consultants to check against the design goals established in phase 1.

(3) **WORK-PLAN PHASE**

This phase goes along with the final specification of the work plan. Detailed computer models and/or physical scaled-down models of the planned space are used to decide on details and final adjustments. Tools have been developed to permit extensive binaural listening tests with those models as well.
Differences of Measured and Simulated Impulse Responses

- Very early "diffuse" components in measured data.
  - Structure of walls > HF
  - Dimensions of walls > LF
- Energy density in specular reflected sound wave for single reflection is much higher.
- Gaps in simulated signal > 3ms can be audible!
- Simulation introduces audible annoying artifacts, particularly with impulsive signals

Measuring a Pre-Set Real Environment

- The measured binaural impulse response fully describes our sound-source position pair:
  - For each change in the surroundings the measurement has to be made.
  - Feasible for non-changing environment.
  - High memory and processing cost required
  - Little knowledge on application required.

Binaural Room Scanning (BRS)
The Complete System

Head-Related Play Back

Binaural Technology (llc)
Experimental Paradigm

A subject is exposed to a virtual space with various (invisible) auditory/tactile objects distributed in it. He/she will localize and identify these virtual objects auditorily, and be able to reach at them and grasp them individually. Upon tactile contact, contour, texture and thermal attributes of the virtual objects will be perceived. It is the task of the subject to manually move the objects around, i.e. to re-arrange their spatial position and orientation according to an experimental plan. Auditory feedback is given.

The SCATIS Lab, an experimental audio/tactile interactive virtual environment

Partners: Aalborg University, Denmark; Bochum University, Head Acoustics, Germany; Pisa University, Scienza Machinale, Italy.

The Scenario of the SCATIS Lab

Architectur of the SCATIS-Lab Virtual-Reality Generator

Schematic of the SCATIS Lab

The SCATIS Glove

SCATIS-Hardware Overview

acquired 1995
requirements:

"smoothness"
frame rate > 16/s
(depending on speed of movements involved)

"responsiveness"
delay < 60 ms

actually achievable with PCs of 2004:
40 sound sources,
moving at moderate speed.
frame rate 20/s
delay 20 ms

List of Events Relevant to the Sound-Field Model

<table>
<thead>
<tr>
<th>Event Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation of the Subject</td>
<td></td>
</tr>
<tr>
<td>Translation of the Subject</td>
<td></td>
</tr>
<tr>
<td>Rotation of the Sound Source</td>
<td></td>
</tr>
<tr>
<td>Translation of the Sound Source</td>
<td></td>
</tr>
<tr>
<td>Modification of the Sound-Source Directivity</td>
<td></td>
</tr>
<tr>
<td>Modification of Surface Properties</td>
<td></td>
</tr>
<tr>
<td>Modification of the Geometry of the Environment</td>
<td></td>
</tr>
</tbody>
</table>

Lehnert, 1994

Filter Structure for the Convolution of „Dry” Signals

arrival time, spectral modification, HRTFs

Doppler Shifts and Visibility Check for Moving Sound Sources

Problems in a Teleconference Setting

Perception of One’s Own Voice

Pörschmann (2001)
Major computational demands arise from the sound-field model which generates realistic room responses, and from the aurilization engine which spatializes primary and reflective sounds. With today’s PCs, up to about 200 sound sources incl. mirror sources can be handled in real time. For distributed sound sources and reverberation dedicated, computationally effective algorithms are usually employed.

A breakthrough toward higher quality and/or lower expense auditory VR displays would require improvement of our understanding of the human subject as a multi-sensory cognitive entity. Dedicated psychophysical and psychological research would be needed to this end.

Virtual Auditory Environments – Auditory Displays

Some Final Statements:

- Implementation of auditory displays for VR systems cannot be done in a straightforward manner. Each component must be examined carefully, and its influence on the overall time lag (preparation time) and the overall frame rate (smoothness) be considered.

- New computational demands arise from the sound-field model which generates realistic room responses, and from the aurilization engine which spatializes primary and reflective sounds. With today’s PCs, up to about 200 sound sources incl. mirror sources can be handled in real time. For distributed sound sources and reverberation dedicated, computationally effective algorithms are usually employed.

- A breakthrough toward higher quality and/or lower expense auditory VR displays would require improvement of our understanding of the human subject as a multi-sensory cognitive entity. Dedicated psychophysical and psychological research would be needed to this end.

Vision of a Multimodal Tele-Conferencing System

Generic Application Areas of Binaural Technology

- a Summary -

1. BINAURAL RECORDING & AUTHENTIC REPRODUCTION
   - entertainment (e.g. audio industry), education, instruction, scientific research, documentation, surveillance, teleconferencing

2. BINAURAL MEASUREMENT & AUDITORY EVALUATION
   - noise control, acoustic environment design, quality assessment & control, specific measurements on telephone systems, hearing losses, personal hearing protection & on hearing aids

3. BINAURAL DISPLAY & VIRTUAL ENVIRONMENT
   - binaural mixing, binaural room simulation, psychoacoustic & statistical processing, mirror sources, virtual environments, virtual acoustics, virtual reality, surgical training, multichannel systems, advanced music/multimedia interfaces

Thank you!

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