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PRESENTING THE "DIAMONDS CHAMBER"

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ABSTRACT

The "Diamonds Chamber (DC)" (Camera dei Diamanti) is a new virtual reality test bench at the University of Ferrara. The present work describes how at first a commercial chamber designed for audiometric testing was fitted with further sound absorbing material and equipped with an audio system consisting of 41 loudspeakers (32 passive, 8 active and a subwoofer). Later a virtual reality headset was included and finally audio and video were merged. The final configuration allows the creation of realistic virtual AV scenarios: the audio playback is achieved by means of HOA (higher order Ambisonics), while the video reproduction is managed by Unity software. An objective methodology, based on multichannel microphones, has been developed specifically to evaluate the performance of sound spatialization. The results in DC are encouragingly positive because the reproduction error for the minimum audible angle (MMA), which was evaluated for both real and virtual single sources, is mostly in the range 1°-4°. These values are not far from the human ability to distinguish two sounds coming from different directions under optimal conditions. Thanks to its performance the DC can be employed in a wide range of applications, spanning from medicine and psychology to industry.

Keywords: *virtual reality, audiovisual environments, sound spatialization, microphone array, loudspeaker array.*

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1. INTRODUCTION

An acoustic-oriented virtual reality laboratory is a testing facility dedicated to psychoacoustic testing. Such a laboratory consists of three fundamental components to achieve realistic virtual audio-visual (AV) scenarios: a loudspeaker array, a video reproduction system, both working inside a physical room which has been treated acoustically.

The following examples provide a comprehensive overview of such facilities among others: The Virtual Reality Lab at Oldenburg University [1, 2], AVIL at the Technical University of Denmark [3], SCaLAr at RWTH Aachen University [4], ALF at the Wright-Patterson Air Force Base [5], Stanza di Matilde at the Burlo Garofolo IRCCS, and the Audio Space Lab at the Turin Polytechnic [6]. Each laboratory is equipped with a distinct number of loudspeakers and a variety of video reproduction systems, including head-mounted displays (HMDs) and projectors that illuminate cylindrical supports.

The "Diamonds Chamber (DC)" (Camera dei Diamanti) is composed of an audiometric booth, 41 loudspeakers, and an HMD. The aim is to achieve maximum versatility in order to explore different areas of application in both base and applied research.

Besides describing the realization of the DC, in this work a methodology is presented to evaluate the sound spatialization performance, with the understanding that it could be useful for similar virtual reality labs during setup and validation.

2. CONSTRUCTION

An audiometric booth (420×318×276 cm – external dimensions) from Puma Acoustics was mounted with an initial layer of melamine foam prisms glued on the walls and on the roof. A very quiet ventilation and floor vibration insulation systems are both implemented in the booth. As a first customization, a metal frame measuring $326{\times}326{\times}220\,\mathrm{cm}$ (see Fig. 1 (A)) was installed to hold the loudspeakers (see Fig. 1 (B)) and a second layer of melamine foam was inserted in the void spaces of the frame (see Fig. 1 (C)). Then, sound absorption of the floor and a chair were added (see Fig. 1 (D)).

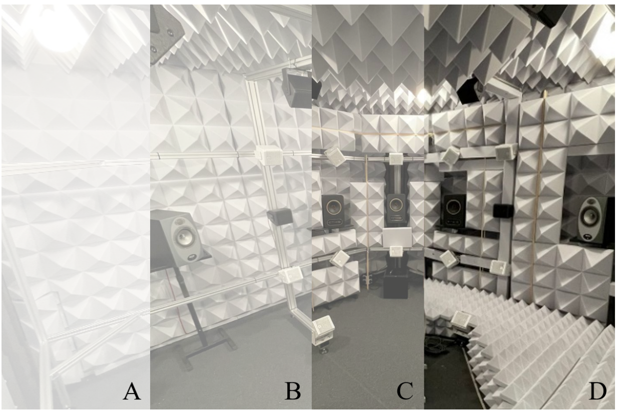

Figure 1. Evolution of DC during the construction with the addition divided into steps A to D.

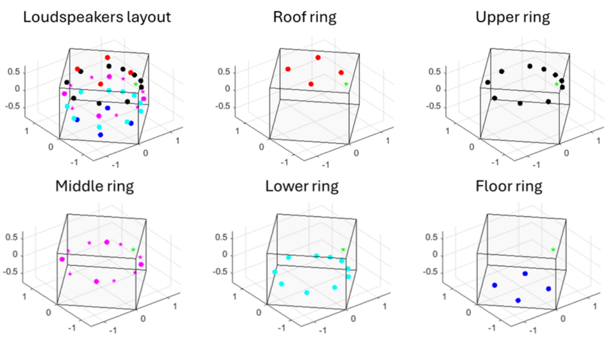

Figure 2. Loudspeaker layout arranged in rings.

Thirty-two passive, eight active loudspeakers, and a subwoofer were installed. Fig. 2 illustrates how they are arranged in five rings. The layout enables audio playback via Ambisonics technology for sound spatialization. This technique is based on the description of the acoustic field through spherical harmonics, with each harmonic corresponding to a specific channel. The Ambisonic Channel Number (ACN) defines the number of channels required for an Ambisonic system of order O:

$$ACN = (O + 1)^2 \tag{1}$$

However, it is possible to achieve a higher order using fewer channels than originally required. To achieve this goal, the AllRAD decoder, developed by Zotter and Frank [7], is employed. This decoder utilizes the VBAP (Vector-Base Amplitude Panning) method, introduced by Pulkki [8], to create virtual sound sources. Thanks to the AllRAD decoder, the DC system can reproduce 7th-order Ambisonic spatial sound using only 40 channels (one per loudspeaker, excluding the subwoofer) instead of the originally required 64.

The audio signal is managed at 48 kHz by an RME Fireface UFX III audio card (eight active loudspeakers) and passed to a digital amplifier, the Innosonix MA32/LP^2 for the thirty-two passive loudspeakers. After decoding, signals are processed to ensure isochronicity and avoid coloration.

3. VIRTUAL REALITY

The virtual reality (VR) system consists of a Meta Quest 3 HMD running Unity applications. Specifically, three demos were developed to illustrate some of the possible practical fields of application, including a spatial audio experience (the audiovisual material is from Cooper [9]), a pointing sound localization test, and an advanced speech audiometric test. The last two tests are intended to serve as primary components of prospective psychoacoustics applications.

The communication between Unity executable and the digital audio workstation (DAW) is managed by an Open Sound Control (OSC) protocol. This configuration allowed the use of WhisPER [10], a MATLAB-based platform, designed to perform diverse psychoacoustic tests.

4. LOCALIZATION PERFORMANCE EVALUATION

4.1 Methodology

An objective methodology, based on multichannel microphones, has been developed to evaluate the sound spatialization performance of audio reproduction inside DC. The method can be outlined as follows:

1. Signal playback from a specific source identified by two "expected" coordinates (EC): azimuth and

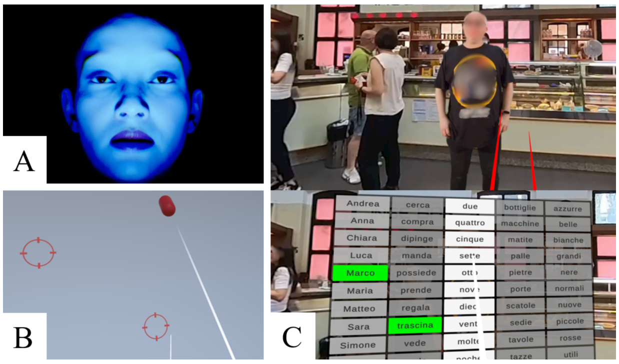

Figure 3. Spatial audio experience [9] (A), pointing sound-localization test (B) and advanced speech audiometry test.

elevation. The directions were specified via the encoder SPARTA AmbiENC and routed to the playback system;

2. Signal recording through an Eigenmike® em64 microphone array having 64 channels and MADI connected to the sound card;
3. Detection of the recorded coordinates (RC) via COMPASS SpatEdit(A) from Aalto University;
4. Calculation of the localization error (LE) as the difference between the positions specified in EC and RC.

The same investigation was conducted for both real sources, that is single physical loudspeakers, and for a set of virtual sources.

4.2 Results

As illustrated in Fig. 4, the LE values are presented as colormaps. The obtained values are positioned at the center of the circles and then interpolated using the natural neighbor method. Specifically, the LE is calculated as the central angle created by the chord between the EC (circles) and RC (crosses).

The results are encouraging and the bias between expected and measured directions is in many cases in a range between 1° to 4°, which is approximately the Minimum Audible Angle (MAA) (see [3, 11–14]).

The method is entirely objective and robust, with the advantage of a smooth integration with the playback/recording chain. Obviously, it does not provide information on what the subjective performance is; on the other hand the obtained LE data validate DC as a suitable platform to run sound spatialization experiments by setting its reproduction limits. A further improvement in this respect is under consideration by implementing a multichannel binaural playback [4].

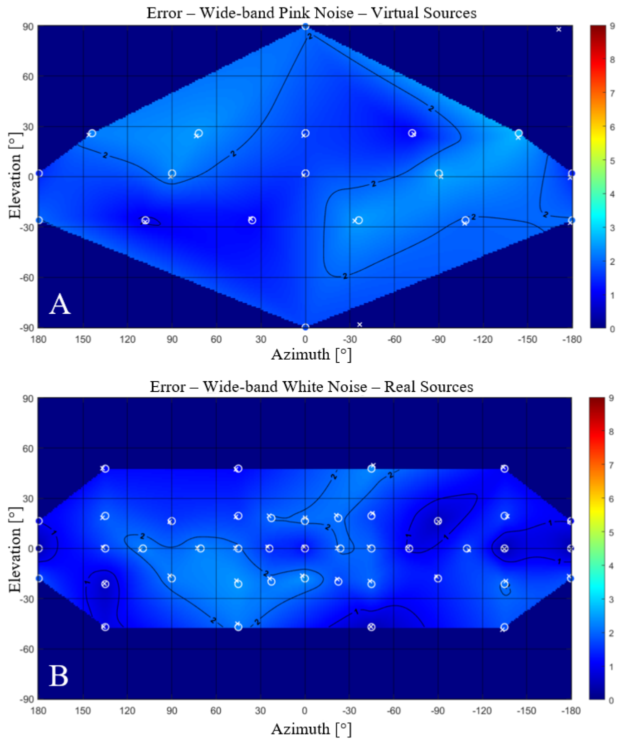

Figure 4. LE for virtual sources (A) and real sources (B). The circles indicate the EC and the crosses the RC. Black isolines enclose areas in which the error exceeds the value indicated on the line.

5. CONCLUSIONS

The “Diamonds Chamber” has been set up to be a state-of-the-art test bench with multifaceted capabilities, encompassing both fundamental and applied research domains. A notable feature of this technology is its scalability, which facilitates precise customization to specific applications by reducing the number of loudspeakers and simplifying the acoustic treatment, rendering it quite affordable. For these reasons, its applications extend to healthcare and industry, offering significant advantages in these fields.

The DC will be further improved in the near future by integrating a pupillometer into the HMD in order to gauge some basic physiological data besides sound-related ones.

6. ACKNOWLEDGMENTS

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