Concept of a Laboratory for Psychoacoustic Experiments with Virtual Acoustics

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Introduction

The ongoing studies on interrelations of virtual acoustics and hearing research we conducted over the past decade [1-8] led us through some pitfalls and avoidable drawbacks before we had established a laboratory that integrates our procedural experiences on the subject. The laboratory now provides the user in an acoustically versatile environment with an integrated and cross-linked infrastructure for conducting physical measurements and perceptual studies with a single or a combination of different audio/video-playback procedures at the same time, all controlled via Ethernet by a single consumer PC. The available audio-playback systems include an individually controlled 96-channel loudspeaker system, conventional discrete multichannel playback systems, and various headphone presentation setups. The laboratory contains a head-tracking system and visual presentation hardware.

In this contribution, the concept of the laboratory is described with a special focus on possible pitfalls, in order to provide the community with additional aspects to be considered when setting up a laboratory or experiments with virtual acoustics in general.

General Concept

For setting up our laboratory, a rectangular about 10.5 m × 3.9 m × 3.3 m (length × width × height) basement room was available. The room has concrete floor and ceiling as well as one concrete wall towards a rather busy street, containing three windows in light wells. Two of the remaining walls are drywall construction, one towards a hallway with heavy machinery and generators on the other side and one towards a workshop. The last one is brick-build towards a stair case. Furthermore, water, drain, and heating pipes lead through the room along its longer axis. These fittings contribute to a considerable background noise floor (cf. Figure 2 below). In order not to increase the background noise further by the equipment required to run the lab (e.g. PCs, amplifiers, video projectors, head-tracking system), and in order to provide a separation between the experimenter and the subjects, we decided to split the room in an experimental room and a control room, separated by another drywall construction. The experimental room then is made up of three drywall and three concrete boundary surfaces (floor, ceiling, one wall).

In the dividing wall, we included acoustically-insulating windows with black-out curtains, an acoustically insulating door, and several closable, acoustically treated cable ducts of different shapes and sizes. The cable ducts have proven to increase the flexibility and widen possible areas of application, as the lab can be adjusted to different needs quickly and easily. For that reason, we found it rather helpful to avoid highly specialized patch bays and keep the possible connections and cable configurations as universal as possible.

The decision to separate experimenter and subject turned out to be of utmost importance for allowing the subjects to focus on their actual task without being distracted during psychophysical experiments, and to keep the background noise during the experiments as low as possible. Both of these aspects are also crucial for conducting measurements in the experimental room. Furthermore, the separation facilitates conducting a series of experiments smoothly in a row, as the experimenter can instruct and prepare the subsequent subject or the next experiment while the current subjects still carries out the experiment. Regarding an easy workflow, high-quality results, and also economic aspects, the separation of control and experimental rooms is highly recommended.

Experimental Room

Figure 1 shows the floor plan of the finished experimental room with exemplary fittings. Note that the projector is located in the control room, behind one of the acoustically insulated windows of the dividing wall.

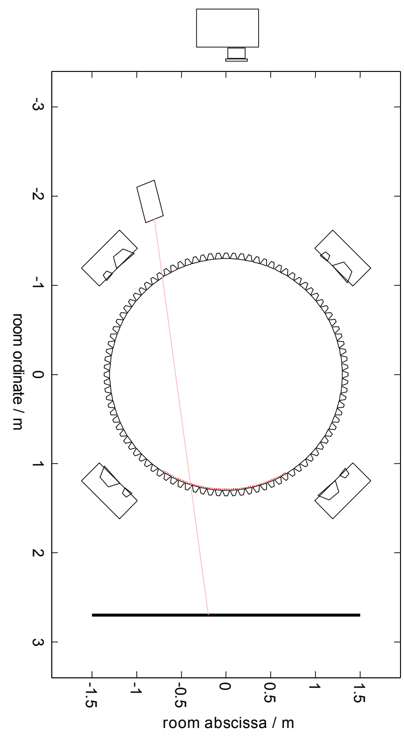

Figure 1: Floor plan of the experimental room with the loudspeaker array, a four studio-monitor speaker setup, laser pointer, projector (in the control room behind an acoustically insulating window) and a projection screen.

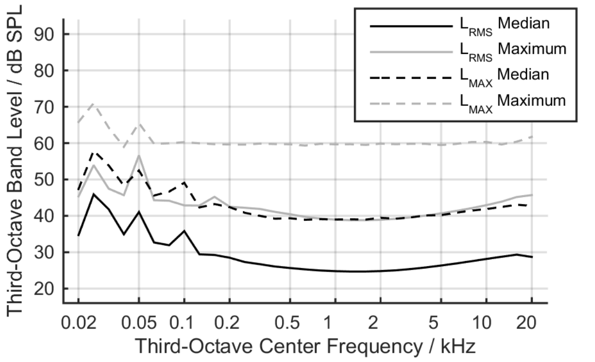

Figure 2: Third-octave band background-noise levels in the experimental room, calculated from multiple measurements collected over a period of three years, with varying overall absorption (21 minutes total). Median (dark) and maximum (light) of RMS level (solid) and maximum level (dashed).

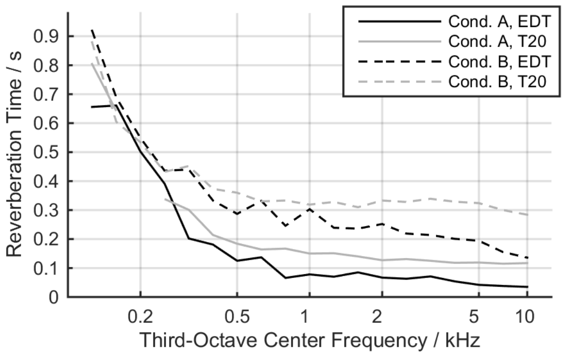

Figure 4: Third-octave band reverberation times (dark: early-decay time EDT, light: reverberation time T20 calculated from the -5 dB to -25 dB decay time) for two different room-acoustic conditions (solid: Condition A, fully closed curtains, dashed: Condition B, mostly open curtains).

The empty experimental room is shoebox-shaped (6.8 m × 3.9 m × 3.3 m), with a volume of about 90 m^3. The background noise level at the typical subject position in the finished experimental room could be kept at an average over different room states (different overall absorption) of about 38 dB(A) or 50 dB SPL, with L_{AFmax} = 52.7 dB (for details cf. the third-octave level statistics shown in Figure 2; all calculations shown in this paper were carried out using [9]).

In the experimental room, removable heavy curtains were mounted at the walls and ceiling. Removable absorber panels behind the curtains were used to further adapt the room to the requirements of the respective experiment, with the intent to provide adjustable and controllable room-acoustic conditions (cf. Figure 3).

In order to give an example of the achievable change of room-acoustic conditions, Figure 4 shows the third-octave band reverberation times (early-decay times EDT and T20, dark and light) for two conditions we used frequently:

A Fully closed curtains, absorbing panels in place (solid contour).

B Mostly open curtains, no absorbing panels (dashed).

Combining curtains and panels, it is possible to control late and early decay frequency dependently. To achieve low-frequency control, additional absorbers are necessary.

Regarding non-acoustical factors, it was attempted to achieve as much control as possible under the given circumstances, not only over the auditory stimuli, but also over the visually applied stimulation; especially intending to be able to conduct experiments on audio-visual interactions in the lab. For that reason, care was taken to allow the experimental room to be completely darkened. This required heavy blinds in front of the windows and seals at all possible “light leaks”, including cable ducts, doorway frames, keyholes and pipe openings. The human eye demonstrates astonishing night-vision capabilities, especially towards the end of a 20 minute or more experimental session in the dark.

In order to control the experiment and to monitor the subjects’ condition despite darkness in the experimental room, an infrared camera system and a voice communication system were installed. Before the experiments, the subjects were informed and had to agree to this supervised procedure.

Technical Equipment

The experimental room contains different installations. Most prominent is an individually amplified and individually controllable 96-channel loudspeaker array with adjustable geometry. To allow a most versatile three-dimensional movement of every single speaker, a rail system was designed (cf. Figure 5, where a circular geometry is shown).

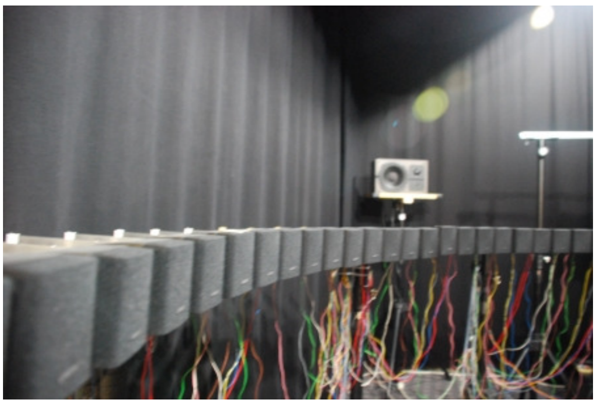

Figure 3: Experimental room with removable heavy curtains and absorbers (behind), allowing to adjust the acoustic conditions as required by the actual experiment.

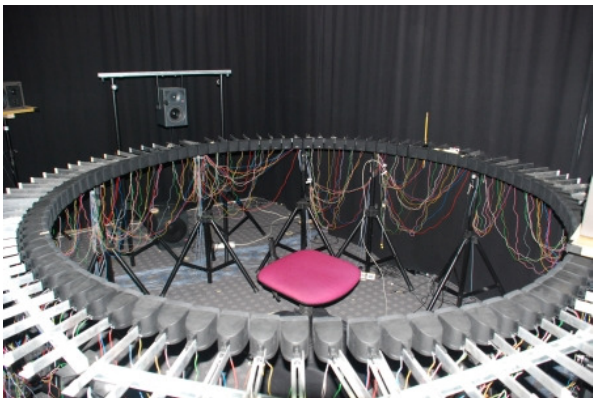

Figure 5: Individually controlled 96-channel, geometrically-variable loudspeaker array installed in the laboratory; here as an example arranged in a circular layout.

Figure 6: Racks in the control room, containing the DA converters (two units at the bottom of each rack) and the power amplifiers used to drive each loudspeaker of the array with its individual signal.

The loudspeaker boxes were connected individually to separate amplifiers located in the control room (cf. Figure 6), using about 8 km loudspeaker cable. The ability to drive each loudspeaker individually was necessary as conducting experiments on wave-field synthesis was one of our primary motivations to set up the lab [10-15].

The amplifiers were in turn driven by DA converters mounted at the bottom of each rack (cf. Figure 6), which were all connected to audio interfaces mounted in a single consumer PC. For that reason, all the audio rendering and the control of the array could be done by a software module running on this PC. The audio interfaces were carefully selected and internally synchronized, in order to ensure sample synchronous operation of all 96 channels.

Regarding the selection of well-suited audio interfaces, we must warn others planning to set up massive multi-channel playback setups: while multi-channel recording is used frequently, in recording studios as well as for measurement purposes, massive multi-channel playback still appears to be more uncommon. That may be the reason why the audio interface we initially chose for driving the loudspeaker array was specified to support the synchronous output of up to 96 channels but did not work for the playback of more than 48 channels at the same time. Recording however worked fine. For that reason, we had to exchange the interfaces including the PC-hardware platform. In order to avoid such pitfalls, Table 1 gives an overview of the hardware we eventually used for most of the psychophysical experiments we conducted in the lab. However, while we found this setup to work well for our purposes, it is certainly not the only equipment suited for psychophysical experiments.

Table 1: Overview of the major technical equipment installed in the lab and used for psychophysical experiments.

Device	Description	Qt
Bose FreeSpace® DS 16S	Broadband loudspeaker box	96
RME HDSPe RayDAT	36-Channel audio interface	3
RME Multiface II	12-Channel audio interface	1
RME Fireface 400	18-Channel audio interface	1
SonicCore A16 Ultra	16-Channel AD/DA converter	6
Samson Servo 120a	Stereo amplifier	48
POLHEMUS FASTRAK®	Motion tracking system	1
Epson EMP-TW 700 LCD	Projector	1
Klein + Hummel O98	Active 3-way studio-monitor loudspeaker box	2
Klein + Hummel O200	Active 2-way studio-monitor loudspeaker box	5
Klein + Hummel O800	Active studio subwoofer	1

Running a loudspeaker system with an output power specified at about 5.5 kW and a specified power consumption of some 12 kW requires at least three 16A/230V power supply lines. For that reason, we had a separate breaker box with several 16A/230V lines installed in the laboratory, right next to the amplifier racks. This turned out extremely helpful for the every-day routine operating the array, as despite a specifically worked out activation sequence, the enlarged power consumption during the turn-on process frequently overloaded the power lines and triggered the fuse. The separate breaker box allowed us to quickly re-arm the fuses (typically, the second try of turning the amplifiers on is successful, as the amplifiers' buffer condensers are charged somewhat then). Furthermore, the multiple-line breaker box allowed us to separate the PC, audio-interface, and DA-converter power supply from the amplifier circuits, while reducing ground loops to a minimum. In order to further reduce the likeliness of electrically induced humming or general noise problems, balanced line connections between audio-interfaces and amplifiers are highly recommended. Combined with optical ADAT connections between audio interfaces and DA converters and the common ground, no audible crosstalk or ground loop occurred in our setup.

Overall, the laboratory including the described hardware setup was ready to use after about 20 months from the beginning of the construction work, that is not including the planning and grant application phase.

System Calibration and Stability

In order to provide reproducible conditions and controlled operation, a massive multichannel loudspeaker setup must be calibrated. As running a calibration procedure for about 100 loudspeakers requires quite some time, the question of stability is also important. We actually calibrated at irregular intervals but verified the level of broadband pink noise intended to create 80 dB SPL at the subject position regularly.

As a measure for the stability of the system, Figure 7 shows for each loudspeaker the range of level corrections we actually applied over a period of about three years in order to transmit broadband pink noise at a defined level to the position of the subject, while keeping the hardware amplification factors constant (solid black: median, solid gray: maximum/minimum, dashed gray: 25/75 percentiles).

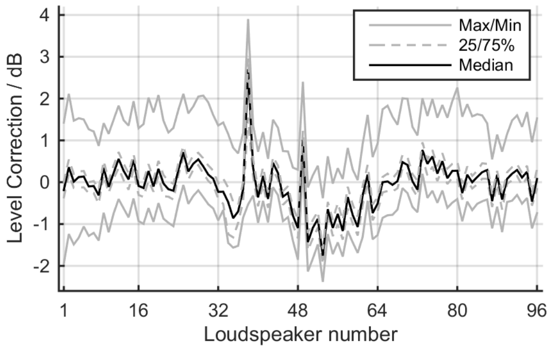

Figure 7: Statistics of level corrections necessary to transmit broadband pink noise at 80 dB SPL to the typical listening position (collected irregularly over a period of about three years with constant hardware amplification factors).

As a measure of the level accuracy we achieved during our experiments, Figure 8 shows the statistics over a period of about three years of our verification measurements with broadband pink noise intended to elicit 80 dB SPL at the position of the subject.

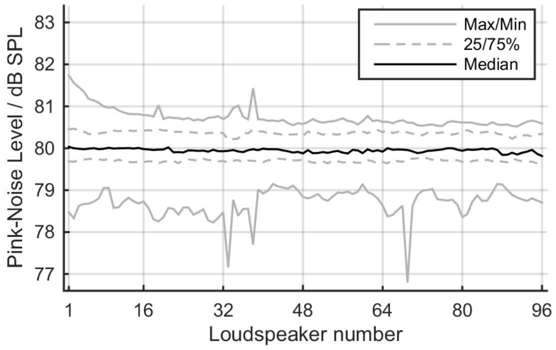

Figure 8: Statistics of the level accuracy achieved over a period of three years with the calibrated system when aiming at eliciting 80 dB SPL with broadband pink noise at the typical subject position (weekly control measurements).

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