Audio Engineering Society

Convention Paper 8305

Presented at the 129th Convention
2010 November 4–7 San Francisco, CA, USA

Progress in Auditory Perception Research Laboratories - Multimodal Measurement Laboratory of Dresden University of Technology

M. Ercan Altinsoy, Ute Jekosch, Sebastian Merchel and Jürgen Landgraf

Chair of Communication Acoustics, Dresden University of Technology, 01062, Dresden, Germany

Correspondence should be addressed to Ercan Altinsoy (ercan.altinsoy@tu-dresden.de)

ABSTRACT

This article presents the general ideas and implementation details of the **M**ulti**M**odal **M**easurement Laboratory (MMM Lab) of Dresden University of Technology. This lab combines VR equipment for multiple modalities (auditory, tactile, vestibular, visual) and is capable of presenting high-performance, interactive simulations. The goals are to discuss the progress in auditory perception research laboratories in recent years and the technical parameters, which should be considered for the implementation of reproduction systems for different modalities.

1. AUDITORY PERCEPTION RESEARCH

Psychoacoustics aims to model the perception of sound. It concerns itself with the relationship between physical sound events and their perception. The data, which is required for investigating and modeling the rules of perception, is gathered through listening experiments. The presentation of an identical stimulus for all subjects in a well-defined acoustical environment should be guaranteed for such kind of experiments. Therefore most of the classical psychoacoustic investigations, such as threshold measurements, auditory masking experiments, etc., were and are still conducted in sound-insulating audiometry booths.

However we perceive our world in a multimodal way. In our daily life we permanently obtain information about products through all our senses during product use. In many situations, such as driving a car, drilling a hole, playing a guitar etc., we are exposed to sound, vibration and visual information simultaneously. Consequently, the cross-modal information has a substantial influence on the perception of the user [1]. Hence a perceived sound is not just a sensation, but also carrier of information from and about the environment – sound has a meaning. For example, in product sound

quality evaluation, the context, the ambience and the interaction play a very important role. Therefore the research in the fields of product sound quality, communication acoustics and semioacoustics requires multimodal interactive simulators which can emulate our daily situations plausibly.
Virtual reality provides the user real-time multi-sensory interaction with the computer-generated environment. Virtual reality generators have proved to be potent tools for research and development. They allow for flexible and economic presentation of complex experimental scenarios which can be modified without any physical effort [2].

2. MOTIVATION AND REQUIREMENTS

Taking into account the above-mentioned aspects, Chair of Communication Acoustics at Dresden University of Technology decided to build a new Multimodal Measurement Laboratory. The main questions addressed in MMM lab are:

- How does a human listener manage to select certain characteristic features from the auditory event and take them as information carrying units, i.e. as sign carriers?

- How do human listeners associate meaning to acoustic-auditory events?

- How does the brain weigh the inputs it receives from the different senses to produce a final percept? In other words, what are the relative contributions of the different sensory modalities to the multimodal percept?

- Can a perception of an event in one sensory modality change due to the presence of a stimulus in another sensory modality?

- How do we perceive product quality globally? How do we judge auditory and tactile product quality separately?

In order to investigate these questions and to simulate different daily-life situations such as driving a car, experiencing a concert or flying with an airplane, we decided to present acoustic, motion, vibration, force-feedback and visual stimuli to the subjects.
Currently developed reproduction technologies were selected for these different modalities. Acoustic stimulation was realized by a wave field synthesis system. The motion and vibration feedback are generated by a six degree of freedom hydraulic motion platform. The visual information is displayed by a Full HD video projector.
In principle, wave-field synthesis (WFS) attempts to simulate the spatial sound-field and it is based on free-field wave propagation. Therefore the reflections of the reproduction room should be suppressed. Theoretically the best reproduction room for the WFS is an anechoic chamber. However anechoic chamber conditions are unusual for most of our test participants (particularly for inexperts) and cause on them estrangement with the experiment which is undesirable for the contextualization. Therefore we decided that the reproduction room should be built according to listening room recommendations rather than anechoic chamber conditions.
One of the important challenges by building a multimodal measurement laboratory is that the reproduction systems for other modalities such as motion, video etc. should be very quiet and don't disturb the acoustic reproduction and environment.

3. LABORATORY COMPLEX

MMM laboratory complex consists of four rooms to conduct perception experiments (Figure 1):

- an instruction room to instruct the test persons
- a control room for the experimenter
- measurement laboratory – reproduction room
- a technique room

The following paragraphs will provide some insight into the technical properties of these rooms.

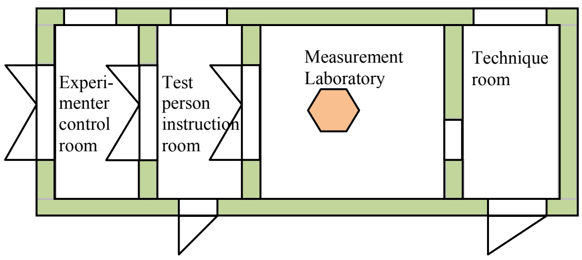

Figure 1: Laboratory complex

4. MEASUREMENT LABORATORY – REPRODUCTION ROOM

It was agreed that the room was to be constructed according to ITU-R BS1116.1 and DIN 15996 recommendations [3,4]. The room shape was selected as rectangular but side walls were inclined by 3° to reduce the chances for flutter echos (Figure 3). Length (l), width (w), and height (h) of the room are 5.8 m, 4.15 m and 3.2m. The dimensions fulfill the ITU aspect ratio recommendations which are:

$$1.1\left({}^{w}/_{h}\right) \leq {}^{l}/_{h} \leq 4.5\left({}^{w}/_{h}\right) - 4 \qquad (1)$$

and

$${}^{l}/_{h} < 3\,;\ \ {}^{w}/_{h} < 3 \qquad (2)$$

The floor area is 24 m^2, which fulfill the recommended minimum floor area for stereo reproduction and is slightly smaller than recommended minimum floor area for multichannel reproduction [3], and the volume of the room is 77 m^3.

Taking into account the reverberation time recommendations of ITU-R BS1116.1 and DIN 15996, acoustical treatments were installed on the walls and the ceiling. If the room attracts the attention of test participants visually, it is non constructive for the experimental contextualization. Therefore the room should be visually unobtrusive for test participants. An absorber system with perforated metal sheets which have light gray color was chosen as treatment. The perforation has an open area of 20%. To realize the varying sound absorption properties, different type of inlays were used (mineral fiber only, additional plastic foil, imperforated metal sheets, Figure 2). The floor was covered with carpet.To minimize the dips and peaks in the room's response in low frequencies, adjustable Helmholtz resonators were installed in the room corners.

Figure 2: a) Mineral fiber treatment b) Plastic foil & min. fib. on ceiling c) Helmholtz resonator at the corner

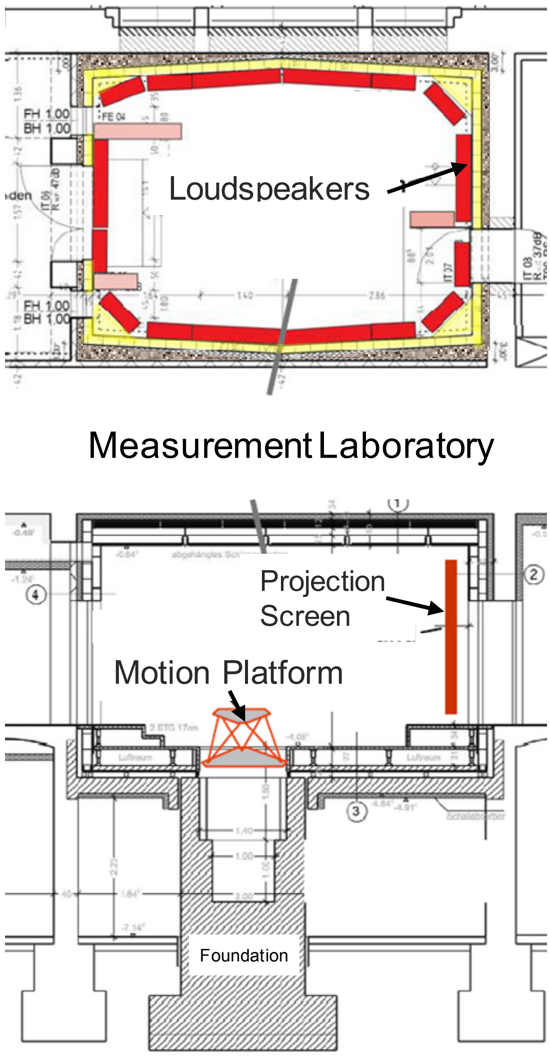

Figure 3: Sectional images of the measurement laboratory with loudspeakers, motion platform and projection screen.

The reverberation time and the uniformity of reverberation as a function of frequency are perceptually important. The reverberation time of the room conforms to the tolerances, which are given by ITU-R BS.1116 & EBU 3276 and shown in Figure 4 [3, 5]. The results are indicating mean values of a total of 8 measurements [6]. The uniformity of the curve is noticeable above 100 Hz. The fine tuning of the Helmholtz resonators allows good reverberation time values at low frequencies.

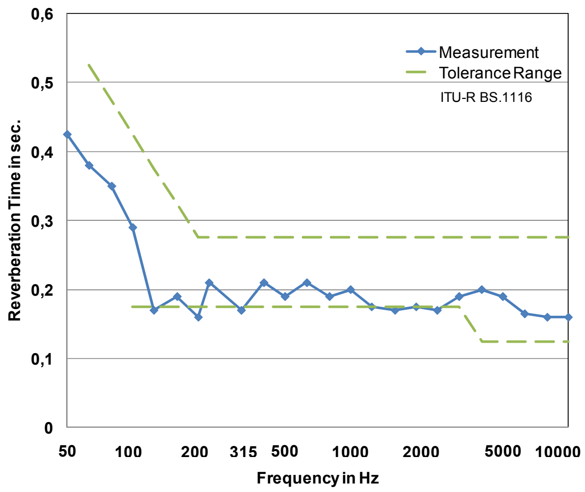

Figure 4: Measured reverberation time and the tolerance range according to the ITU-R BS.1116.

Besides of reverberation time, background noise and sound insulation are important issues for the measurement laboratory. The background noise level should be minimized. Targets for the sound insulation were defined according to OIRT recommendation R53 for broadcast studios.

To reduce the transmission of vibration and structure-borne noise within building, a room-in-room construction was selected. The space between old masonry and the inner shell of the room-in-room construction was filled by 10-20 cm mineral fiber. Both floor and walls are supported by longitudinal beddings (Fig. 5).

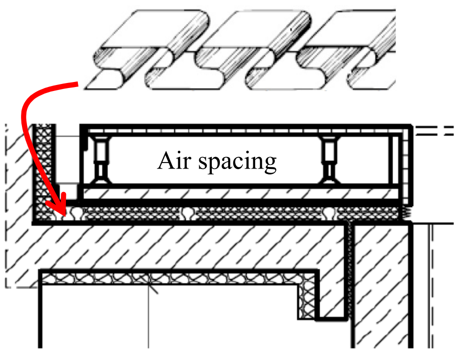

Figure 5: Longitudinal beddings for elastic decoupling.

A floating pavement (app. 10 cm) was constructed and installed underneath of the floor for the suspension. It was necessary to install an efficient and very quiet air conditioning (HVAC) system. Perforated floor plates were installed to guarantee enough ventilation openings for a low air velocity. A raised floor with a spacing of 27 cm is provided for air supply and as well as cable installations (Figure 5). HVAC units were installed in another room which does not have any common walls with the laboratory. An elastic foundation was used for HVAC machinery.

To interrupt the vibrations, which can be generated by motion simulator and transmitted into the room, the simulator obtained a separate ferro-concrete foundation (Figure 3). The space between the foundation and floor of the room is filled with the mineral fiber to avoid the sound transmission from below.

A cross-talk sound attenuator is installed to reduce the low frequency sound transmission between two adjacent rooms.

Figure 6 shows the measured background noise levels in different operational conditions. The results indicate that the extensive sound insulation treatments enable us to meet the recommendation requirements.

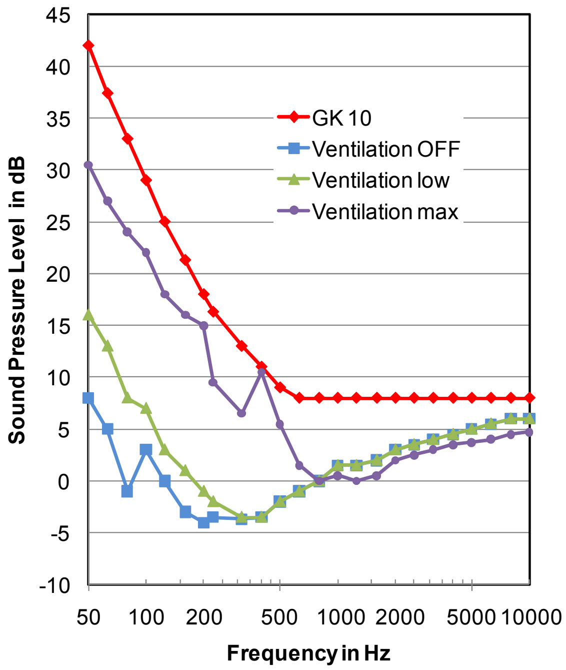

Figure 6: Measured background noise level in different operational conditions and the threshold GK 10 according to the DIN 15996 which until 630 Hz corresponds to the NR 10 curve of the ITU-R BS1116-1 recommendation.

The measured weighted sound reduction indexes are 74 dB (wall from corridor to lab), 72 dB (ceiling), 48 dB (door to lab). The weighted normalized impact sound levels are 32 dB (ceiling) and 32 dB (corridor floor to lab).

5. WAVE FIELD SYNTHESIS SYSTEM

The wave field synthesis (WFS) was chosen as audio reproduction system. The reasons for this decision were:

- to create a virtual auditory scene over a large listening area,
- produce plane waves that are localized in the same direction throughout the entire listening area,
- enhance the localization of virtual sources, the sense of presence and envelopment through a realistic reproduction of the amplitude distribution of a virtual source,
- to create focused sources in the field between the listener and the loudspeakers[7].

An IOSONO WFS reproduction system was installed to the laboratory. This system consists of 464 loudspeakers and 4 subwoofers. Loudspeaker panels, which consists of 8 channels (6 tweeter, 2 bass/midrange driver), are shown in Figure 7. The theory of WFS assumes a spatially continuous distribution of secondary sources which is not practically implementable. Therefore some spatial aliasing artifacts occur in the reproduced wave field [8]. To reduce the aliasing artifacts, the tweeter loudspeakers were installed with a very little spacing of 6 cm, which is the smallest spacing in up to now installed WFS systems. Each individual loudspeaker (468 separate channel) is driven by wave field synthesis signals generated from the incoming audio signals and spatial parameters assigned to each sound source.

Figure 7: Loudspeaker panels for WFS system.

The amplifiers of the loudspeakers are placed into the air spacing (Figure 5).

Simultaneous rendering of 32 virtual sound sources (focused source, point source or plane wave) is possible. Maximum delay is about 30 ms. Object-based authoring plug-in IOSONO Spatial Audio Workstation (SAW) allows the experimenter to easily create and edit complex sound scenes (Figure 8). Using SAW, the motion paths can be created, moved, rotated, scaled and grouped.

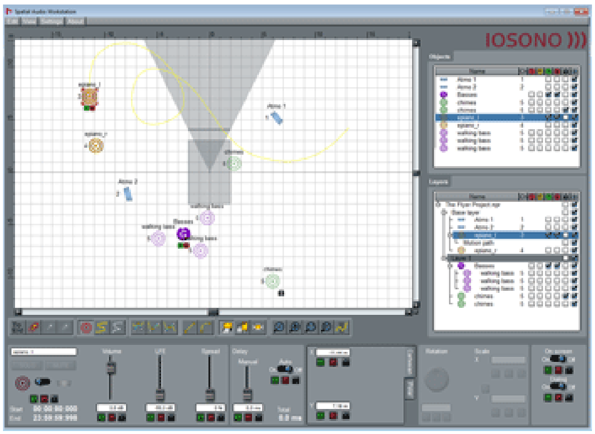

Figure 8: Screen shot of the IOSONO Spatial Audio Workstation.

The control unit manages all central functions: audio server functionality, signal processing, and a routing system that handles internal and external connections. Using 8 rendering PCs, the signal processor computes the wave field synthesis algorithm in real time. To avoid the noise of PCs, they are placed in technique room (Figure 1).
A room simulation modul is implemented either to import and use the measured room impulse responses or to simulate different soundfields. The simulation is based on the mixture of perception and physical based models. In order to enable 3D analysis and processing of impulse responses in a room, a prototype spherical array measurement system was developed for our lab by Fraunhofer Institute, TU Ilmenau and TU Delft. A microphone mounted on a mechanical arm moves along a Lebedev distribution of discrete positions on a spherical surface [9].
In some cases wave field synthesis but also higher order ambisonic may meet some limitations, the combination of both sound spatialisation technologies is very promising. Therefore the loudspeaker setup will also be used for higher order ambisonics reproduction. Combination of the stereophony and WFS can also provide solutions for the WFS limitations [10].

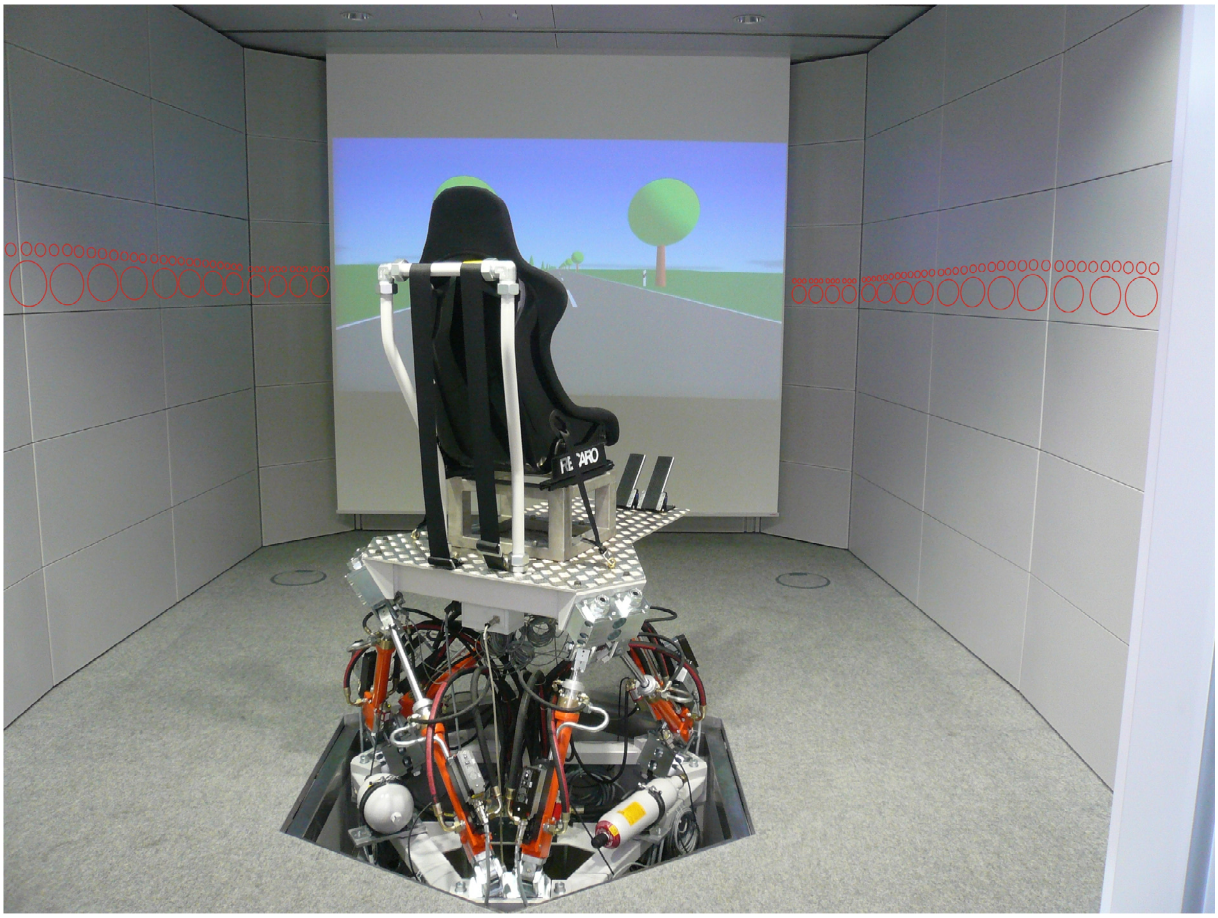

Figure 9: The motion platform in MMM Lab.

6. MOTION PLATFORM

Sound and vibration perception are always coupled in live music experience. Just think of a rock concert or hearing (and feeling) a church organ sitting on a wooden pew. Our recent studies showed that whole body vibrations improve the perceived overall quality of concert DVD reproduction [11]. To generate such kind of whole-body vibrations and to mimic motions which we are exposed while travelling by car or airplane, a six-degree-of-freedom hydraulic motion platform was installed in laboratory (Figure 9). It was built and designed after the Stewart platform principle. The main disadvantage of motion platforms is the high level noise which occurs when they generate signals. For this reason, the hydraulic pump and the actuator were placed in another room.

An axial pump was chosen to achieve requested dynamic properties. The novel valves allow generating not only low frequency vibrations but also high frequency vibrations. The frequency range of the platform is 1-200 Hz. The motion system capabilities are shown in Table 1.

The payload of the motion platform is 250 kg. The platform can produce vibrations up to 8g (short-term) and 1.5g (long-term).

Low noise generation was very important for our application. Therefore during the selection of aggregate and auxiliary components such as valves, cylinder, etc., our criteria were noise and dynamic properties. To reduce volume and pressure variations in hydraulic systems, a silencer (pulsation damper) was installed.

To eliminate the transmission of vibration, the platform was mounted on a separate basement as above mentioned.

max. translation	z-axis	407.6mm
	x-axis	+/- 270.0mm
	y-axis	+/- 311.5mm
max. rotation	yaw	+/- 30.0°
	pitch	+/-27.0°
	roll	+/- 30.0°

Table 1: System capabilities of the motion platform

In some experiments, it is necessary to use the measurement lab only for audio reproduction. In such cases the motion platform is not needed. Therefore a hole was built on the platform foundation (see Figure 3). The platform can be hidden in this hole in park situation.

7. VISUAL DISPLAY

For the visualization, a Full HD video projector (2D) was chosen. In most cases, high-quality two-dimensional visual information is absolutely sufficient to contextualise the subjects. As projector screen, an acoustically transparent woven screen was chosen in order not to disturb wave field synthesis.
Although the video projector is very quiet, a soundproof box was built for the projector.

8. STEERING WHEEL, PEDALS AND FORCE-FEEDBACK DEVICE

As input devices for driving applications, a steering wheel and two pedals (acceleration and breaking) were chosen. A potentiometer measures the current steering angle, other two potentiometers measure the position of the pedals.
The Cyber-Grasp force-feedback system is used to present force-feedback information generated from haptic interactions. The force-feedback system consists of a force-reflecting exoskeleton and a hand-tracker glove, and provides force-feedback to each finger of the user relative to the palm of their hand (Figure 10).

9. SOFTWARE

Software toolboxes were developed for MATLAB to control audio, motion platform and video reproduction. Using MATLAB toolboxes, it is possible to control all WFS parameters and synchronous playback of the 32 audio channels. It is also possible to control the parameter of the motion platform (displacement x, y, z and rotation roll, pitch, yaw).

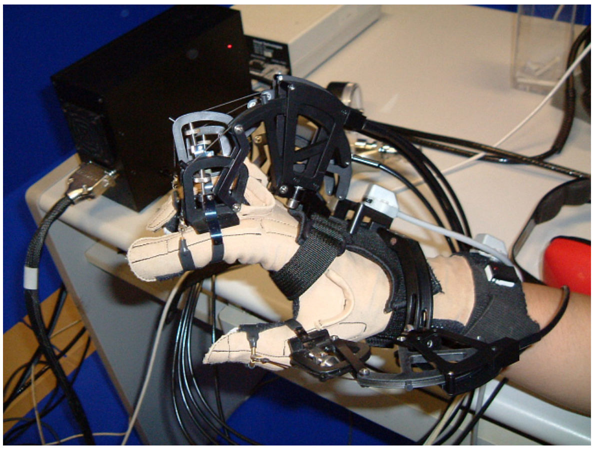

Figure 10: Cybergrasp force-feedback system [1].

The reason for the selection of MATLAB was twofold. First reason is that our chair has a MATLAB-based software package for performing listening tests which was developed over the years. Second reason is that the students, who prepare a B.Sc. or M.Sc. thesis and want to use MMM lab, don't need to have extended capabilities for software programming.

10. SUMMARY

In this article, we presented the Multimodal Measurement Laboratory of Dresden University of Technology. In recent years, the importance of the contextualization and multimodal interaction on the auditory perception research were noticed. The research in the fields of product sound quality, communication acoustics and semioacoustics requires the simulation of our daily situations plausibly. Therefore we need the virtual reality technology, which provides the user multi-sensory interaction, more and more. Currently developed technologies such as WFS or broad band vibration reproduction through a hydraulic motion platform, were successfully applied in the realization of MMM lab. This lab with many special characteristics fulfill the requirements of the researchers. Very little spacing between the loudspeakers for WFS reproduction or separate foundation for the motion platform are some of the such kind of features. In sum, the MMM lab is usable for closed and open-loop perception experiments.

11. ACKNOWLEDGMENTS

The authors are very grateful to Dr. A. Roy and Dr. H.J. Ederer from Akustik Bureau Dresden, for their outstanding supervision of the laboratory. We would like to thank Prof. Dr.-Ing. Dr. techn. h.c. Jens Blauert for all his support and the valuable discussions. We are also grateful to DFG, Dresden University of Technology and Sächsisches Immobilien- und Baumanagement. Furthermore we would like to thank the companies OHE and IOSONO GmbH.

12. REFERENCES

[1] Altinsoy, E., Auditory-Tactile interaction in Virtual Environments, Shaker Verlag, Germany, 2006.

[2] Blauert, J., Analysis and synthesis of auditory scenes, Communication Acoustics, pp. 1-26, Springer, Berlin-Heidelberg-New York NY, 2005.

[3] ITU-R Recommendation-BS.1116-1 second edition, Methods for the subjective assessment of small impairments in audio systems including multichannel sound systems. International Telecommunications Union: Geneva, Switzerland, 1997.

[4] DIN 15996, Elektronische Laufbild- und Tonbearbeitung in Film-, Video- und Rundfunkbetrieben – Anforderungen an den Arbeitsplatz *[Image and sound production in film and video studios and radio stations - Principles and provisions for a work station],* Deutsches Institut für Normung, 2007.

[5] EBU Tech. 3276, 2nd edition, Listening conditions for the assessment of sound programme material, European Broadcasting Union, 1997.

[6] Roy, A., Landgraf, J., Room acoustics, sound insulation design and supervision for a multimodal measuring laboratory, in Int. Conf. on Acoustics (NAG/DAGA 2009). Rotterdam, The Netherlands, 2009.

[7] Spors, S., Rabenstein, R., Ahrens, J., The theory of wave field synthesis revisited. In 124th AES Convention, The Netherlands, 2008.

[8] Theile, G., Wave Field Synthesis – A promising spatial audio rendering concept, Proc. of the 7th Int. DAFX-04, Italy, 2004.

[9] De Vries, D., Microphone arrays for measurement and recording, in Proceedings of the 19 th International Congress on Acoustics, Madrid, Spain, 2007.

[10] H. Wittek. Perceptual enhancement of wavefield synthesis by stereophonic means. Journal of the Audio Engineering Society, 55(9), September 2007.

[11] Merchel, S., Altinsoy, M.E., Vibratory and Acoustical Factors in Multimodal Reproduction of Concert DVDs, in Altinsoy, M. E., Jekosch, U. & Brewster, S. (Eds.), Haptic and Audio Interaction Design 2009, LNCS 5763, pp. 119-127. Berlin, Germany: Springer, 2009.