International Conference

Headphone Technology

Aalborg, Denmark August 24–26, 2016

CONFERENCE REPORT

Sponsored by

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Between August 24 and 26, 159 scientists, developers, and practitioners from all over the world gathered in Aalborg, Denmark, for three days to attend the Headphone Technology conference. In the venue of a renovated power plant, the delegates were updated on the state of the art in headphone technologies through 17 demonstrations as well as 26 oral and 6 poster presentations allowing the industry to meet academia and discuss the future of headphone technology. The conference covered various topics from the measurement and characterization of headphones, through spatial audio and binaural reproduction, to the perceptual evaluation of the headphones and assistive listening devices.

Keynote 1: Wolfgang Klippel: Micro-Speakers—Hybrids between Headphones and Loudspeakers

During the opening keynote of the conference, Wolfgang Klippel walked the audience through the modeling of transducers for regular loudspeakers and headphones and compared it against the emerging field of micro-speakers. Most engineers prefer the simplicity of the lumped parameter models, where moving-coil transducers are approximated as linear, time-invariant systems. Such models are typically sufficient for regular loudspeaker drivers, but are found lacking for headphone transducers and especially micro-speakers. Phenomena such as lossy inductance, creep of the suspension, modal vibrations of the diaphragm, and the influence of the air surrounding the micro-speaker were discussed and put in context of the lumped parameter model. In his conclusion, Klippel highlighted the effects of the compliance and the modal vibration patterns of diaphragms as being parameters of particularly high significance for micro-speaker performance.

Keynote 2: Volker Hohmann: Auditory Signal Processing for Assistive Listening Devices (ALD)

Wearing a hearing aid is associated with a social stigma, and it is estimated that 75% of people suffering from a hearing loss do not use a hearing aid. According to Volker Hohmann, the future of the hearing aid industry includes helping people with minor to moderate hearing loss. Introducing hearing aid technologies in consumer electronic devices for assistive listening and improving sound quality in such devices could help increasing social acceptance of hearing aids. User satisfaction is a key parameter in getting people with mild to moderate hearing loss to adopt the technology, which can help them. Hohmann's group at Oldenburg has developed an acoustically transparent earpiece and works with methods allowing the users to adjust the assistive listening algorithms for personal preference. In the future, Hohmann predicts that the smart phone could be a powerful tool in combination with assistive listening devices and hearing aids, empowering the users to adjust their device for personal preference.

Wolfgang Klippel

Volker Hohmann

Keynote 3: Veronique Larcher: Some Trends and Their Impact on Headphone Development

Veronique Larcher introduced the audience to several trends in global society that will affect the future demands of headphone technology. Growing concerns for environmental sustainability and scarcity of resources such as magnetic material, has led to research in these materials. Results from such research fields includes advances in recycling of magnetic material, magnetic strength improvements of 10–40%, and new manufacturing techniques such as 3D printing that enables new possibilities for designing headphones. Another growing trend is health awareness. People are willing to ingest smart pills to monitor their health and improve their focus, memory, etc. Similar diagnostics might be obtainable using EEG sensors coupled to headphones, if consumers can accept the associated design and discomfort of the electrical stimulus emitted by the sensors. Finally, the restlessness of generation Y was related to emerging consumer habits. Their desire for freedom and spontaneity opens the market for live streaming events such as concerts via virtual reality allowing the audience to be on the stage with the performers. These are some of the trends, which will affect consumer demands and headphone design in the future.

Keynote 4: Andrew P. Bright: Headphones, Known-Knowns and Unknown-Unknowns

What design target should one use when designing new headphones? With his keynote, Andrew Bright reviewed what prominent features are related to the experienced sound quality of headphones. When defining a design target for headphones, it is reasonable to seek similarities between headphones that are generally deemed good. Comparing frequency response measurements of "good" headphones indicates that a slight bass boost and slight treble cut is preferable. However, a listening test, conducted by the acoustic consultancy company Delta, divided the listeners in two groups: one with a preference toward a flat frequency response and one preferring a small bass boost. Another question is how well objective headphone measurements correlate with the sound human test subjects experience. Studies have shown that there is an overestimation of the 2–3 kHz range in the IEC711 (60318) ear coupler, relative to human subjects. This was attributed to the straight cylindrical approximation of the ear canal used in the coupler. Results from the literature show such resonances in the ear canal to be much more prominent for listeners wearing closed headphones relative to open headphones. This indicates that the interaction between ear-canal acoustics and headphones is likely a key parameter to control in order to obtain the desired sound quality.

PAPERS

Headphone Design

Following the opening keynote, Isao Anazawa gave a paper presentation on the topic of electromagnetic interference (EMI) in headsets. Concerned with EMI below 50 kHz, Anazawa compared 21 headsets and found large variations in the applied cabling and corresponding EMI performance. The recommendation was to carefully apply shielded microphone cables, a feature lacking in five of the tested headsets. Victor Benichoux followed this by reaching out to the audio engineering community. Representing a group of neuroscientists, he presented an active earplug design for chinchillas. The purpose of the earplug is to investigate the neural adaptation due to chronic exposure to signal degradations, such as gain differences between the ears. Their current silicone plug offers insufficient reduction of external sound for the planned experiment. Benichoux finished his presentation with a request for feedback on their design and was promptly rewarded with suggestions for alternative hardware platforms.

Headphone Personalization

Head-related transfer functions (HRTFs) and binaural reproduction were big topics at this conference. Rishabh Ranjan introduced the audience to a procedure for measuring HRTFs with a freely moving listener. This was accomplished using adaptive filtering with update rules for improving the estimates at previously calculated head orientations. The results showed rapid acquisition of HRTFs based on simulated data from the CIPIC database, and further work will involve applying the algorithm to real recorded data. Online available HRTF databases were also the basis for the two following presentations on the topic of interaural time differences (ITDs), given by Andrea Genovese. In the first presentation, ITDs extracted from the databases CIPIC and LISTEN were analyzed to reveal asymmetry between incidence from the left and right of the listener. For the second presentation, the ITDs were used to estimate the interaural distance assuming a spherical model of the head. Compared with head widths in the databases a 3 cm average offset was found. It was argued


A capacity audience welcomes Klippel's opening keynote.

that the estimated interaural distances follow the anthropometric trend as the distribution of estimated head widths follow the same trends as actual head widths. Jianjun He followed with a similar idea: Is it possible to infer anthropometric features from a set of measured HRTFs? A model was trained, assuming linear relationships between HRFT features and anthropometric features. From the results, it was seen that the best features for anthropometric prediction is HRTF log-magnitude, interaural level difference, and ITD.

A challenge for augmented reality is to merge virtual sound sources seamlessly with the environment surrounding the listener. To solve this, Rishabh Ranjan presented an adaptive filtering strategy to continuously monitor and equalize the response of a pair of headphones to the wearer. Jan Rennies agreed that headphones and listening devices should be adapted to the user, especially for users with impaired hearing. His presentation on adaptation of hearing aid algorithms was a comparison between four different interfaces for users to adjust the algorithms in their hearing aids. The users were asked to select their preferred spectral emphasis preset and adjust the input level to a three-band compressor. The users preferred direct control of the two parameters to guided test procedures with forced choice. It was seen that the users were consistent in their self-fitting but that preferences were different, emphasizing the relevance of personalization.

Jan Rennies, center, receiving the prize for the best paper from papers cochairs Alexander Lindau, left, and Juergen Peissig.

The award for the best poster went to Todd Welti, left.

David Ackermann of TU Berlin, right, receiving the award for best demonstrator.

Binaural Technologies

To ease the task of binaural recordings, César Salvador presented a method to synthesize binaural signals from recordings with a spherical microphone array. The theoretical accuracy of the spherical array was compared to boundary element simulations of a head. While the accuracy generally depends on the number of microphones, it was seen that there exists a limit beyond which increasing the microphones does not improve the accuracy any further. Philipp Stade also sought to simplify binaural recordings. He presented a parametric model for synthesizing late binaural reverberation in order to reduce the data stored for Binaural Room Impulse Responses (BRIRs). The model uses a predefined mixing time after which the reverberation is synthesized from energy decay curves in frequency bands and the interaural coherence. Perceptual evaluations showed that the performance of the synthesis depends on the choice of mixing time, the resolution of the filter bank, and interaural coherence matching.

Standards

Christopher Struck gave an overview of headphone test methods specified in IEC 60268-7 and identified areas that could be simplified or improved. A suggested measurement sequence included measuring two-tone intermodulation distortion and averaging five transfer function measurements to mitigate the effects of positioning dependence of the headphones on a dummy head. Morten Wille introduced suggestions for improvements to the IEC 60318-4 ear-simulator. To provide an ear-simulator for low-noise measurements and better fit of in-ear headphones, a new ear-simulator was presented. The ear-simulator included a new pinna and ear canal based on anthropologic data from 260 people. The presented results indicate improved repeatability in headphone measurements relative.

Perceptual Evaluation

Tore Stegenborg-Andersen initialized the perceptual evaluation session with a comparison of seven prototype headphones. The sensory profile for each pair was determined from experiments using both the actual headphones and a simulated reproduction from a HATS measurement presented through a pair of reference headphones. The bias from physical differences of the headphones was reduced by using a single brand and similar designs. The study conducted by 18 expert assessors showed statistically significant differences between the two experiments for six out of seven elicited attributes. Christer Volk used the simulated reproduction data in the effort to relate the sensory evaluation to objective measurements of the headphones. It was concluded that the timbral attributes "Bass Strength," "Clean," and "Dark-Bright" could be modeled by the loudness in given frequency ranges relative to the broadband loudness of the stimulus. Chris Pike continued the descriptive analysis talks by presenting a comparison of binaural rendering methods. Pike compared convolution with binaural impulse responses (BIRs) against amplitude panning between two virtual loudspeakers before convolving with the corresponding BIRs. The results showed the differences were mainly related to tonal coloration and source direction. Samuel Moulin presented a qualitative descriptive analysis of loudspeaker responses presented through dynamic binaural rendering. The purpose was to introduce a base line for future investigations of less-time-demanding approaches for descriptive analysis. The results showed that the expert listeners were able to find differences between the loudspeakers with the given sound

Buffet lunch on the first floor of the venue (a former power plant)

samples. Therefore, the measured dataset was judged suitable for future investigations of rapid experimental procedures.

Digital Signal Processing

To kick off the digital signal processing session, Sean Olive presented a method for determining the preferred low-frequency boost of in-ear headphones. Ten trained listeners adjusted level and center frequency of a 2nd-order low-shelving filter to their preference. The results showed that the preferred level of the shelving filter was 9.9 dB, which is 5.1 dB higher than what was found in a previous study on circumaural headphones. Pablo Gutierrez-Parera followed this with an investigation of how headphone frequency responses affect azimuth localization accuracy. Seven headphones were compared as simulations over a pair of reference headphones. It was concluded that an irregular response in the 4–7 kHz range degraded the localization accuracy.

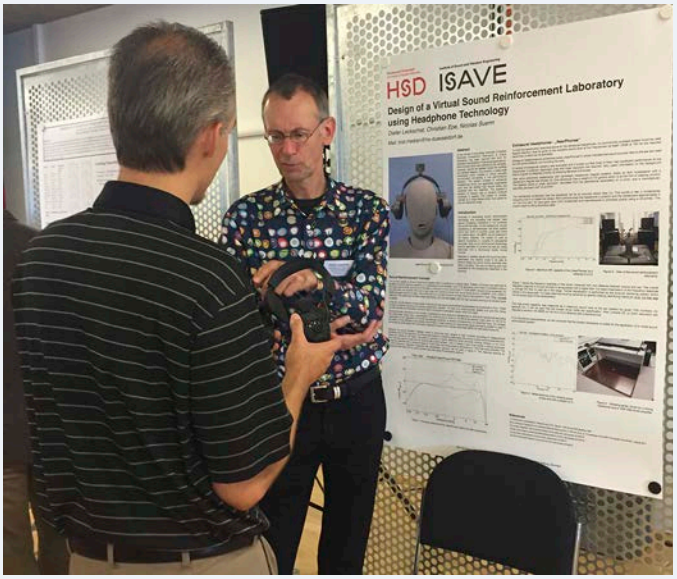
Reproducing stereo recordings over headphones can be improved through binaural rendering of a stereo loudspeaker setup. Javier Gómez-Bolaños presented a study on how to compensate for the cross-talk differences between a loudspeaker stereo reproduction and the binaural rendering of it. Jianjun He presented a different view on how channel-based material can be converted into binaural renderings. He introduced a hybrid model to extract spatial components from a base sound file, by identifying primary and ambient sound components. An emerging interest in binaural reproduction is how to protect copyrighted BRIRs. Johannes Arend presented a method for watermarking BRIRs through coded echos hidden in the reverberation tail of the room impulse response. Perceptual tests showed that rooms with long reverberation time provided a more stable watermark but with reduced acoustic transparency compared to dry rooms.

A prototype headset with hear-through functionality was presented by Juho Liski. The hear-through algorithm was adaptively estimating and compensating the transfer function of external sound through the headset. The algorithm can improve the hear-through of sound from the frontal direction in case of a poorly fitted headset, but off-axis sound is colored due to lack of directional processing.

Active Noise Canceling and Listening Comfort

State-of-the-art active noise canceling (ANC) headphones utilize active cancellation below 1 kHz and passive dampening above. While a closed design is beneficial for the passive dampening, it compromises wearing comfort and introduces occlusion. Hatem Röschmann-Foudhaili presented a semi-open ANC headphone design for improved comfort. By carefully controlling the opening of the headphone, the effective range of ANC is increased to 7 kHz, and cancellation performance similar to closed-headphone was achieved. The drawback of the design is a reduced sound quality. This is due to the opening and back cavity of the headphones being optimized for ANC purposes rather than high sound quality. A different talk was given by Jay Kirsch on the suppression of burst noises, as found when releasing the talk switch in communication systems such as radios. These bursts are usually of much higher amplitude than the target speech and can be painful to listen to over a pair of headphones. It was seen that it is possible to characterize and suppress burst noise while retaining the speech signal. Safe listening levels for headphone reproduction was the theme for Dorte Hammershøi's presentation. Currently, there does not exist a standard for visualizing the hazard users are exposed to when using a personal music player. Experimental results have shown sensitivity differences of 15–20 dB between headphones. To provide accurate dosage estimates, it was suggested to include music genre, headphone sensitivity, and headphone frequency response in the estimate. How to introduce this data is debatable, but audio track metadata combined with an online database for headphone characteristics were proposed solutions.

Natural presentation of the surrounding sound is a prominent factor for the listening comfort of hear-through hearing instruments. To evaluate the hear-through of a prototype hearing instrument, a new evaluation method was proposed by Florian Denk. The stimulus is generated as a dummy head recording of the hearing instrument in an ambisonics-rendered sound field. The recording can then be presented binaurally to test subjects. Using this method, the prototype performed similarly to an idealized reference and outperformed a standard behind-the-ear hearing aid.



Dieter Leckschat demonstrating the design of a virtual sound reinforcement laboratory.

Juha Backman listening to the TU Berlin demo.

Tapio Lokki, right, having a discussion with Florian Denk.

Alexander Lindau experiencing BBC's interactive VR piece "The Turning Forest."

Peter Larsen showing the Loudsoft software for measuring active noise control performance of headphones.

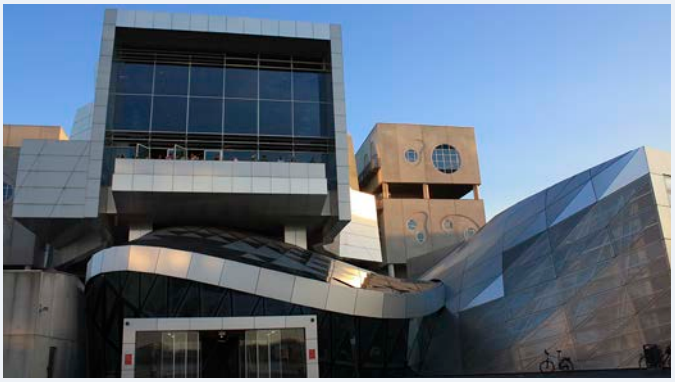
POSTERS AND DEMONSTRATIONS

A time slot was reserved for the delegates to attend poster presentations and demonstrations each day of the conference. Even with access to the demonstrators and posters for the entire conference, the attendees were pressed for time to experience all of the 17 demonstrations and six posters. The posters covered topics such as holistic user experience evaluations of headphones, virtual design of PA studio monitors, and evaluation of bass preference for in-ear headphones. The demonstrations included examples of binaural recordings (some with accompanied virtual reality), audibility of nonlinear distortion in headphones, and headphones automatically adapting to the wearer. These demonstrations displayed state-of-the-art as well as emerging headphone technologies and allowed industry and academia alike to meet and discuss future possibilities.

SOCIAL EVENTS

Musikkens Hus

On the opening day of the conference, the delegates walked across the street of the conference venue to the concert hall Musikkens Hus (the house of music), completed in 2014. Here the delegates were greeted by the vice-mayor of Aalborg and introduced to the design and chosen solutions in the construction of the concert hall. After the presentations, the participants were encouraged to peruse the building and enjoy the amazing view of the waterfront during a prolonged Danish sunset. A light meal accompanied a mixer party and allowed the delegates to network to their heart's content.



The side of Musikkens Hus facing the waterfront with the conference attendees enjoying the sunset from the balcony.

The robbers' camp in the middle of Rold forest.

The conference committee: from left, Sean Olive, Jürgen Peissig, Martin Olsen, Jens Schönemann-Paul, Patrick Hegarty, and Alexander Lindau.

Awards were given for the best paper, poster, and demonstration. The best paper award was given to Jan Rennies for "User-Interface Concepts for Sound Personalization in Headphones." The prize for the best poster was awarded Todd Welti for "A Validation Study of a Method for Virtualizing In-Ear Headphones," and the best demonstration was "Presentation of Interactive Recordings of Beethoven Symphonies" by TU Berlin.

Conference cochair Patrick Hegarty thanked the presenters, demonstrators, sponsors, and delegates for their contributions to present, demonstrate, and discuss the future of headphone technology. AES past-president Jan Abildgaard Pedersen took the stage and thanked the participants for their contributions to make AES the place where academia and industry meet to shape the future of audio technology.

Jan Abildgaard Pedersen taking the stage and delivering some final word.s

AES THANKS HPT COMMITTEE

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Editor's note: the papers presented at this conference can be obtained from http://www.aes.org/publications/conferences/

Robbers' Camp

For the banquet, the delegates were transported by bus from Aalborg to Rold forest, 30 min. outside Aalborg. Here, they were ambushed by the infamous robbers of Rold forest and guided through the mesmerizing late summer forest of gnarled and twisted trees to the robbers' camp in the heart of the forest. After being greeted with a glass of mead and a robber's feast, it was time for games. The delegates were challenged to prove their worth in feats of ax throwing, archery, and log sawing. As the participants had had their fill, it was back to the buses under a clear night sky, guided by the stars and a gravel road.

CONCLUSION AND AWARDS