Sven Nordholm, Walter Kellermann,
Simon Doclo, Vesa Välimäki,
Shoji Makino, and John R. Hershey

Signal Processing Techniques for Assisted Listening

Natural hearing is a desirable goal in many electronic communication applications, such as hearing aids, audio conferencing, gaming, and virtual reality applications. The era of low-power, high-complexity electronics supports the implementation of computationally complex algorithms as needed to provide a more natural listening environment for the advanced augmentation of virtual reality and natural content.

As such, assisted listening techniques provide the means to communicate audio information from devices to human listeners. The main objective is to provide the user with a listening experience through the device that resembles natural hearing of the sound information. Prominent applications include virtual augmented audio, hearing aids, and cochlear implants. But the same techniques are also applicable in other communication applications such as monaural voice communication, where additional spatial information can greatly enhance the listening experience. In the realm of hearing aids, current devices aim to be more natural both for the hearing impaired and profoundly deaf by using new processing techniques. They even promise to enhance the listening experience of so-called normal hearing users. Along with increasingly affordable and growing computer power, a large variety of elaborate algorithms for overlayed audio or so-called augmented audio continuously strive toward new applications in gaming and telepresence to provide a "being there" experience.

The articles in this special issue of *IEEE Signal Processing Magazine* (*SPM*) focus on three main aspects of signal processing in this domain: audio enhancement, presentation/rendering, and evaluation. To limit the scope in this special issue, machine-learning techniques have been excluded. While it is understood that future systems for assisted listening will greatly be influenced by machine-learning-based algorithms, another special issue dedicated to this development can already be envisioned.

THE MAIN OBJECTIVE OF ASSISTED LISTENING TECHNIQUES IS TO PROVIDE THE USER WITH A LISTENING EXPERIENCE THROUGH THE DEVICE THAT RESEMBLES NATURAL HEARING OF THE SOUND INFORMATION.

Audio signal enhancement, particularly of speech signals, has a long research tradition and still dominates the scene, and, consequently, is also the main topic of this special issue. Techniques for single-channel and multichannel signal enhancement techniques play a preeminent role in telecommunication, hearing aids, and augmented headsets. Accordingly, fundamental problems and state-of-the-art techniques are presented in the article "Multichannel Signal Enhancement Algorithms for Assisted Listening Devices" by Doclo et al. Beyond the description of the generic algorithms, this article emphasizes the specific problems and solutions for hearing aids and headsets addressing both the signal acquisition and the binaural rendering aspect.

As a special technique for capturing and describing the spatial information relevant for assisted listening, multichannel techniques that estimate the direct path information and suppress a combination of reverberation and diffuse noise are provided in the article "Parametric Spatial Sound Processing" by Kowalczyk et al.

Two articles provide overviews on highly relevant aspects of single-channel enhancement techniques: "Optimizing Speech Intelligibility in a Noisy Environment" by Kleijn et al. focuses on techniques for improving speech intelligibility using perceptual criteria and auditory modeling, and "Phase Processing for Single-Channel Speech Enhancement" by Gerkmann et al. provides a survey of techniques that utilize both amplitude and phase information for speech enhancement.

Processing and coding signals for cochlear implants is addressed in the article "Sound Coding in Cochlear Implants" by Wouters et al. This article describes signal processing techniques used in cochlear implants to map the information extracted from an audio signal onto cochlea excitation that a profoundly deaf person can understand.

Rendering of audio aims at providing an immersive, undisturbed listening experience for recorded information via loudspeakers or headsets with typical applications demanding high-quality sound reproduction, such as, e.g., home theaters, gaming, or telepresence systems. Betlehem et al. provide an overview of techniques to deliver audio information to multiple listeners via loudspeakers in their article "Personal Sound Zones." These techniques also have applications in providing audio in public areas without disturbing the surroundings. Then the natural sound in the environment is augmented by the rendered audio. A similar concept to augment outside information using personal headsets is presented by Välimäki et al. in "Assisted Listening Using a Headset," which also

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reviews audio enhancement techniques for music listening in a noisy environment. A third article in this area, "Natural Sound Rendering for Headphones," by Sunder et al., is an overview of techniques for rendering via headsets for applications in three-dimensional audio.

Finding methods for the evaluation and prediction of speech and audio quality is a central task for anyone working in audio signal processing. As subjective evaluations are resource intense and time consuming, it is highly desirable to find objective methods that closely match subjective measures. Objective methods provide instant feedback and results become reproducible. In their article "Objective Quality and Intelligibility Prediction for Users of Assistive Listening Devices," Falk et al. provide an overview of algorithms for objective quality and intelligibility evaluation for hearing aids and cochlear implants.

AUDIO SIGNAL ENHANCEMENT, PARTICULARLY OF SPEECH SIGNALS, HAS A LONG RESEARCH TRADITION AND STILL DOMINATES THE SCENE, AND, CONSEQUENTLY, IS ALSO THE MAIN TOPIC OF THIS SPECIAL ISSUE.

We sincerely thank all of the authors for their high-quality contributions and are grateful for the reviewers for their invaluable help in selecting and improving the articles in this special issue. We also thank Fulvio Gini, special issues area editor, and Abdelhak Zoubir, *SPM's* past-editor-in-chief, for their constant support, patience, and guidance in the process of outlining, soliciting, and reviewing the selected articles. Our appreciation also goes to Rebecca Wollman for her administrative guidance in the process.

We hope that you will find this special issue useful and inspiring for your work! [SP]

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