Analysis of the Influence of Repositioning Hearing Aids on Interaural Time Difference (ITD) Errors of Bilateral Directional Microphones in Hearing Aids

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Abstract

Hearing impaired persons often can localize sounds better without than with hearing aids [1, 2]. One reason may be that some hearing aid algorithms modify the interaural cues intentionally or as an artifact. As a consequence, this can not only lead to a reduced localization performance, but may also reduce the speech-reception benefit of binaural noise reduction systems. To investigate the effect of typical hearing-aid processing on interaural cues in more detail, this study analyses the interaural time difference (ITD) error introduced by standard bilateral directional microphones. Results show that the ITD error shows a typical frequency-dependent pattern that depends on the dummy head type and the individual head shape, but is not so much affected by repositioning the hearing aids. A comparison of ITDs with the interaural group delay (IGD) reveals that the ITD error at the low frequencies is partly described by a constant phase error/offset, but also by some quantity, which remains in the IGD error. The results provide hints for potential strategies of compensating the ITD error.

Introduction

The localization of sound sources is an essential ability of the human auditory system. It is a vital factor for spatial awareness and for the segregation of speech in noise. A decreased localization can endanger people especially in environments such as traffic. Yet, hearing aid technology is not capable of enhancing the localization performance of hearing impaired people. The opposite is the case: the performance of hearing aid users in localization experiments decreases when they are wearing hearing aids. The human auditory system uses interaural differences for the localization of sounds. Depending on the direction the path from a sound source to the two ears can differ in length. This results in interaural time differences (ITD) and interaural level differences (ILD). For broadband stimuli ITDs are dominant for localization [4]. In hearing aids with bilateral directional microphones ITD errors may be introduced by the signal processing. A common example for binaural signal processing is the delay-and-subtract beamforming, which represents a large class of directional hearing aid algorithms. It is a signal processing technique in which outputs from an array of microphones are time delayed so that when they are subtracted from each other a particular portion of the sound field is attenuated. This study investigates the effect of head shape and repositioning hearing aids on the ITD error caused by bilateral directional microphones.

Methods

Stimuli

For the generation of test stimuli with and without hearing aid signal processing, a database of head related impulse responses (HRIR) was created. Therefore, the impulse responses of a sound source at a distance of 1.5m from the center of the head were recorded with the front and back microphones of a pair of Siemens Acuris P behind the ear (BTE) hearing aids. The HRIR were measured using the logarithmic sine sweep method [3]. The 24 loudspeakers were placed on a circular array, providing an azimuth resolution of 15 degrees. The measurement was performed using two different artificial heads (KEMAR, Cortex) and a human head. On each head, the measurement was repeated three times to see the effect caused by using different head shapes, since hearing aid users have different head/body shapes but also mainly to analyze the effect on the ITD error after repositioning the hearing aids on the different heads used. For the first experiment the hearing aid was placed behind the ears, for the second the hearing aid was removed and replaced behind the ears, for the third experiment the hearing aid was removed and slightly tilted behind the ears. A database was then obtained containing HRIRs for the artificial dummy heads (KEMAR, Cortex) and the human head. A speech signal of a female speaker was convolved with the HRIRs of the front microphones, to create the unprocessed test signal, and with the HRIRs of the front and back microphones, to generate the input signal of the hearing aid algorithm.

Figure 1: General setup for the impulse response measurements.

Hearing aid signal processing

In the delay-and-subtract algorithm the back microphone signal was subtracted from the delayed front microphone signal. The delay was 43.82μs, corresponding to a microphone distance of 14.9 mm. A sub-sample delay was realized in the spectral domain, using a short-term Fourier transform (STFT).

Calculation of interaural cues

The interaural phase delay (IPD), interaural level difference (ILD), interaural time delay (ITD) and interaural group delay (IGD) were derived from the interaural transfer function (ITF). The ITF was estimated using an STFT. The time signal is split into overlapping fragments. A von-Hann window is applied on each time fragment, followed by Fourier transformation. The ITF was averaged across time. A weighting function $w(f,t)$ is used before averaging:

$$w(f,t) = \sqrt{|X_l(f,t)|^2 \cdot |X_r(f,t)|^2} \tag{1}$$

where X_l and X_r are the left and right spectra. In each frequency band the average ITF is represented as:

$$ITF(f) = \frac{1}{\sum_t w(f,t)} \sum_t w(f,t) * ITF_{st}(f,t) \tag{2}$$

All interaural cues can then be derived from the averaged ITF:

$$IPD(f) = \angle(ITF(f)) \tag{3}$$

$$ILD(f) = 20\log_{10}(|ITF(f)|) \tag{4}$$

$$ITD(f) = IPD(f)/f \tag{5}$$

$$IGD(f) = \frac{1}{2\pi}\frac{\mathrm{d}(IPD(f))}{\mathrm{d}f} \tag{6}$$

Definition of an error measure

An error measure was defined based on the frequency dependent difference between the interaural cues of the hearing aid processed signal and the unprocessed signal. The ITD error and IGD error as a function of azimuth was defined as the RMS average across frequency in the range from 0 to 707 Hz.

Results

Interaural Phase Difference as a function of frequency

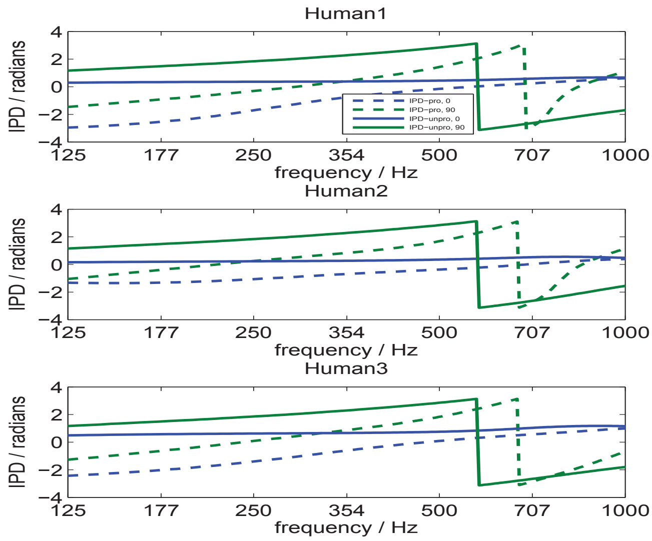

Figure 2: IPD as a function of frequency with re-positioning for a human head. The dashed lines show the processed conditions, while the solid lines show the unprocessed conditions at different azimuths (blue (0°) and light green(90°)).

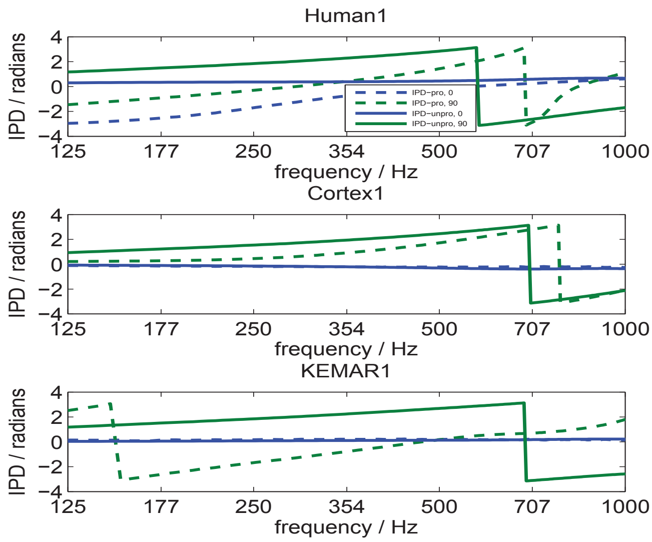

Figure 3: IPD as a function of frequency analyzing the effect of head type. The dashed lines show the processed conditions, while the solid lines show the unprocessed conditions at different azimuths (blue (0°) and light green(90°)).

Figure 2 shows the plot of the IPD as a function of frequency for the human head and its repositioning while Figure 3 shows the plot of the IPD as a function of frequency analyzing the effect of different head types. Figure 3 and Figure 2 show a noticeable phase difference for the low frequencies between 125Hz to 707Hz, followed by a regular pattern phase shift for both the processed and the unprocessed cases. In Figure 2 above 707Hz there is a constant phase shift in all the plots for the human head and its repositioning while the phase shift in Figure 3 varies per head used and this noticeable phase offset can be seen in the results of the processed condition. As azimuth increases from 0° to 90° the phase delay becomes higher. This phase delay probably could be due to a fixed phase error or phase offset at the very low frequencies.

Interaural Time Difference error as a function of azimuth

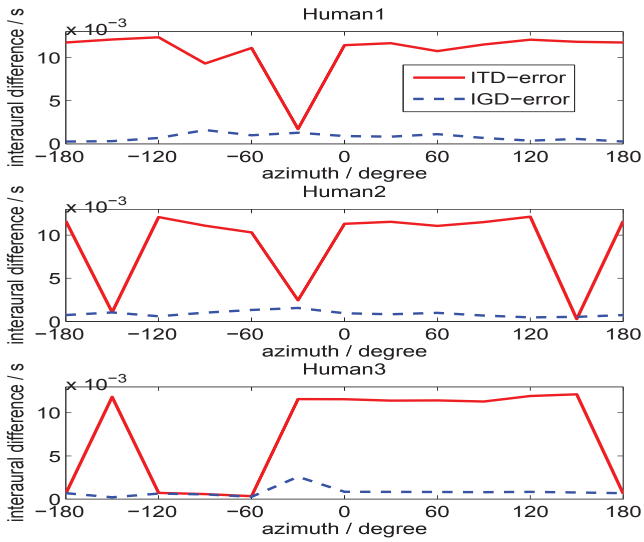

Figure 4: ITD error(red solid line)/ IGD error(blue dashed line) as a function of azimuth with re-positioning for the human head

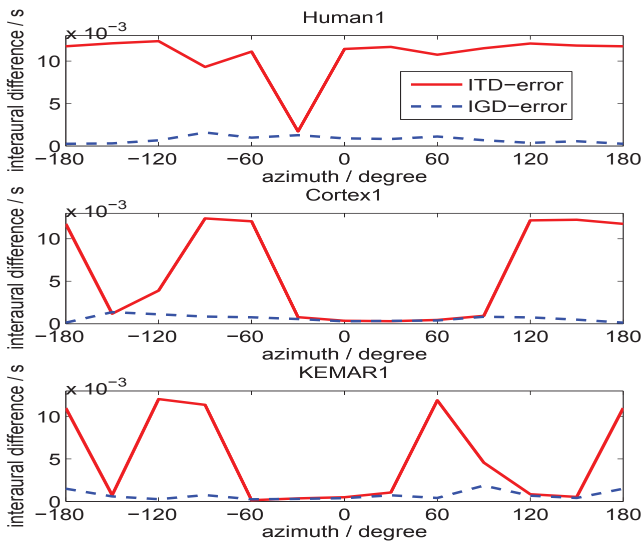

Figure 5: ITD error(red solid line)/ IGD error(blue dashed line) as a function of azimuth analyzing the effect of head type.

Figure 4 above shows the ITD error (red solidline) and IGD error(blue dashed line) as a function of azimuth for the human head and its re-positionings. The ITD error against azimuth is high for the Human head and its repositoning. Head/ear shapes and their sizes both contribute to reflections and defractions around the head/ear leading to the changing spatial structures for the different heads. Figure 4 also shows an IGD error which not constant with a value of ±2ms for all the heads.

Figure 5 above shows the ITD error (red solid line)/IGD error(blue dashed line) as a function of azimuth analyzing the effect of different head types. The ITD error is high for the human head but lower for the KEMAR and Cortex dummy heads. The different head/ear shapes and their sizes both contribute to the different reflections and defractions around the head/ear leading to the changing spatial structures for the different heads. Looking at the ITD error with repositioning from Figure 4 and the ITD error caused by the different dummy heads used, it is plausible to say that repositioning does not have a noticeable effect on the ITD error but rather on the spatial structure of the Interaural difference error. Figure 5 also shows an IGD error which is not constant with a value of ±2ms for all the heads.

Interaural Time Difference error as a function of frequency

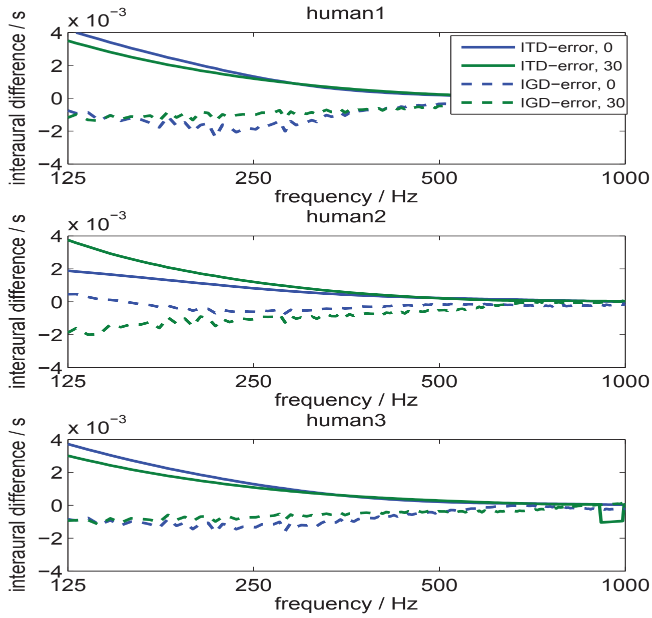

Figure 6: ITD error/ IGD error as a function of frequency with re-positioning for the human head at different azimuths(blue(0°), green(30°)).

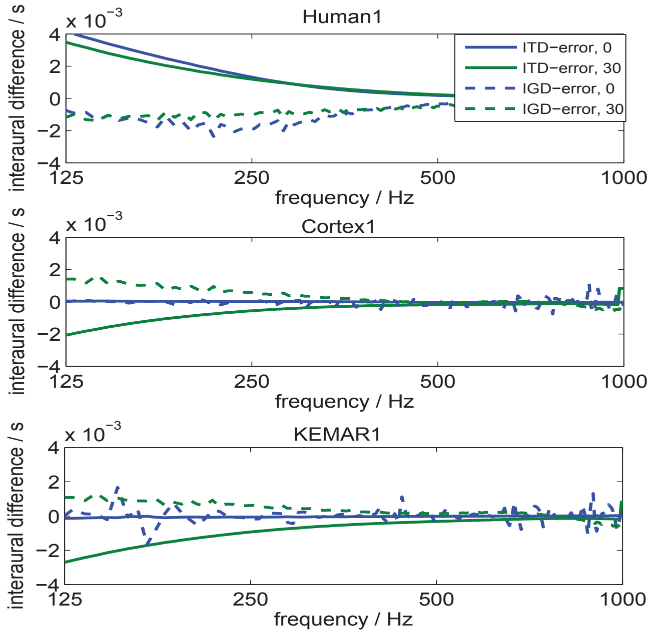

Figure 7: ITD error/ IGD error as a function of frequency analyzing the effect of head type at different azimuths(blue(0°), green(30°)).

Figure 6 shows the plot of the ITD error as a function of frequency for the human head and its re-positioning at azimuths 0° and 30°. From this result there is a high and similar ITD error of $\pm 4ms$ in the lower frequencies between 125Hz to 707Hz for the human head and its re-positionings. The ITD error is frequency dependent and this dependence is only at low frequencies between 125Hz to 707Hz. Usually at low frequencies the ITD is similar to the IGD for the unprocessed condition.

Figure 7 shows the plot of the ITD error as a function of frequency analyzing the effect of different heads at azimuths 0° and 30°. The ITD error is high for the human head with a value of $\pm 4ms$ for the lower frequencies between 125Hz to 707Hz and the KEMAR and Cortex head types have values of $\pm 3ms$ and $\pm 2ms$ respectively in the same range. The ITD error is frequency dependent and this dependence is only at low frequencies between 125Hz to 707Hz. Usually at low frequencies the ITD is similar to the IGD for the unprocessed condition. From theory it is expected from the definition of IGD from equation 6 that, if the plot of IGD error as a function of frequency is zero, then the conclusion that the interaural time delay at low frequencies is caused mainly by a fixed phase offset or phase shift is plausible. But the results show that it is not zero. Hence the ITD at low frequencies is not caused solely by a phase offset but also by some quantity which remains in the IGD error.

Conclusion

The ITD error as a function of frequency shows a frequency dependency which is a characteristic to each head shape, but only marginally depending on the repositioning. The fact that the ITD error is large at low frequencies and vanishes at high frequencies together with the finding that the IGD error is much smaller for all frequencies indicates that the ITD error is mainly caused by a constant phase shift. However, the IGD error is not zero, which suggests that the ITD error can not be solely explained by a constant phase shift.

The results provide hints for potential compensation strategies: Since the ITD error is not dependent on repositioning but rather dependent on the dummy head type and the individual head shape, hearing aid manufacturers could compensate the ITD errors per head since the hearing aids will be the same the next time the hearing aid user puts them on.

References

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