Feedforward Control for ANR In-Ear Headphones and the Use of Artificial Heads

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Abstract

Noise induced hearing loss is a big problem of our society which gets loader and loader. Especially in the working environments people suffer from noise. The government reacts to this by new regulations which lower the allowed daily noise level. Hence even more people need hearing protection devises. Many companies resort to passive working earplugs or earmuffs to reduce the noise. But this also complicates for example the communication between two co-workers. Next to the passive hearing protection devices also commercial active noise reduction (ANR) headsets are available. This headsets use out-of-phase antinoise to reduce the sound pressure level. Whereby commercial headsets use static feedforward or feedback control strategies, academic researches deal with adaptive feedforward filters and so achieve high attenuations. But right now this is only used for circum-aural headsets. To convert these experiences to in-ear headphones first of all a testing environment is needed to minimize the experiments with probands. Therefore the head and torso simulator (HATS) is investigated if it can be used to test different control strategies. This is done by comparing the optimal feedforward filter of the HATS and different humans. Furthermore the differences between the probands are analysed to get conclusion for the future work.

Keywords:
Active noise reduction, active noise cancellation, ANR headsets, head and torso simulator, artificial head

1 INTRODUCTION

The call for hearing protection devises (HPDs) to eliminate hazardous or annoying noise got louder and louder. In particular in Germany new noise protection regulations reduced the allowed daily noise level from 85 dB(A) to 80 dB(A). So even more people need insulating HPDs. Passive working HPDs often suffer from unpleasant fitting and a lack of communication possibilities.

ANR (Active Noise Reduction) Headsets use out-of-phase antinoise to cancel disturbing acoustical noise. On the market different supra-aural and circum-aural headsets with different control strategies exist. The headphones use either feedback control or feedforward controls. Nowadays hybrid controls which combine both strategies show best results in broadband noise attenuation. Furthermore the use of digital adaptive filters in ANR applications becomes common in research. Next to the supra-aural and circum-aural headsets also in-ear headphones with stable non-adaptive feedforward controller arrive at the market. But their attenuation does not show as good results as headphones with earmuffs.

In this paper we investigate the use of a head and torso simulator as a test fixture to evaluate control strategies for in ear headphones. Thereby the optimal filter is not just investigated between humans and the test fixture, also the differences between different humans are considered to allow predictions for optimal control.

1.1 Feedforward Control of In-Ear headphones

The use of feedforward controller for active noise reduction headsets is well-established. A simplified block diagram of this control strategy for in-ear headphones is shown in figure 1. A high attenuation is improved through the passive dampening. Therefore the earphone has to have a good fit in the ear canal, so that the eardrum is sealed from the environment. The headphone is equipped with a reference microphone outside the ear, which receives the disturbing noise via the plant P1. This is then guided through the feedforward filter (FF) and output on a loudspeaker. After the secondary plant S the outputted sound interferes with the noise of the outer signal path P2 at the eardrum.

To cancel the whole sound the optimal feedforward filter results to

$$FF = -\frac{P2}{P1 \cdot S}. \qquad (1)$$

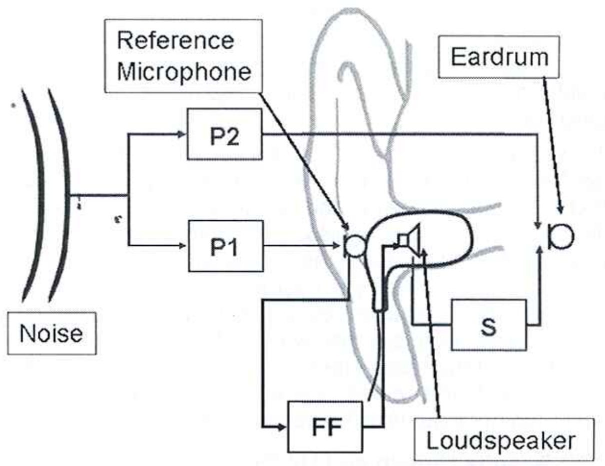

Figure 1: Simplified ANR system with feedforward control, © IMR

1.2 Head and Torso Simulator

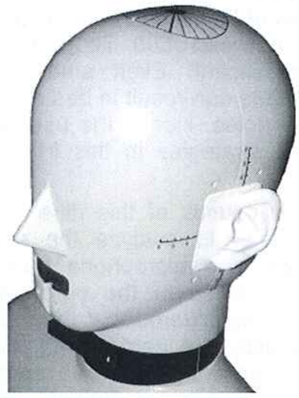

Figure 2: Head and Torso Simulator Type 4128 of Brüel and Kjaer, © IMR

To minimize experiments with humans to evaluate control strategies for in-ear headphones a artificial dummy head with an ear simulator is needed. Therefore the Head and Torso simulator (HATS) of Brüel and Kjaer is investigated if it meets the requirements. It is depicted in figure 2. The mannequin with a build in ear simulator is build as an average human adult with realistic acoustic properties according to the product data sheet [1].

The use of artificial heads, like HATS, for measuring hearing protector attenuation was investigated in different researches. Thereby the insertion loss (IL) at the HATS is compared to the standard measuring technique: real-ear attenuation at threshold (REAT). IL is the difference of for example the sound pressure level at a reference point with and without the hearing protection devise. Especially the use of form earplug show a poor approximation of REAT [2]. However the HATS can be used to compare different earplugs, but can not give exact attenuation measurement. It has to be investigated how much this effects the optimal feedforward filter.

2 COMPARISON HUMAN AND HATS

2.1 Experimental setup

The commercial available ear canal phones CX 300 of Sennheiser are used to compare the optimal filter of the HATS with probands. They are characterized by a high attenuation of ambient noise. In addition this headphones got equipped with outside attached reference microphones.

To determine the optimal feedforward filter of the HATS, equation (1) can be used. Therefore the plants P2, P1 and S are measured with a spectrum analyzer by broadband noise excitation and the filter is calculated. This measurements are only possible because of the build in microphones, which represent the human eardrum.

To evaluate the optimal feedforward filter of a human adult a test setup was build up. Thereby a proband has to find the right amplitude and phase values of the optimal filter at certain frequencies. The manual adjustment is required to really cancel the sound at the eardrum. This can not be ensured by a microphone even close to the eardrum like it is used by the microphone in real ear (MIRE) technique, another way to determine the hearing protector attenuation. Afore was assured that the switch from broadband noise excitation to mono-frequency noise did not influence the optimal filter results.

2.2 Results Human and HATS

In figure 3 the bode plot of the optimal feedforward filter of the HATS is printed in a continuous line. The dots stand for the optimal filter adjustments of different probands. It can be seen that in certain frequency ranges, like between 100 Hz and 600 Hz, the amplitude and phase values of HATS and humans are quite similar. But especially between 600 Hz and 2000 Hz the difference is significant. Even small divergences in amplitude and phase can result in bad attenuation or can even amplify the noise. Hence the use of the HATS to test ANR control strategies in this frequency range is insufficient.

To determine the causes of this differences the MIRE technique was used to analyze the single plants of probands. Therefore a microphone had to be placed inside the ear as close to the eardrum as possible. Thereby had to be considered that the microphone does not represent exactly the eardrum [2]. But it could be seen that the plants P1 and S represent a good approximation of an average human. The differences result from the insufficient modeling of the plant P2. This does not effect the free field characteristics. Only if the ear canal is sealed a resonance establishes and produces this superelevation and phase error. This is the same problem which influences the measurements of the insertion loss of ear plugs.

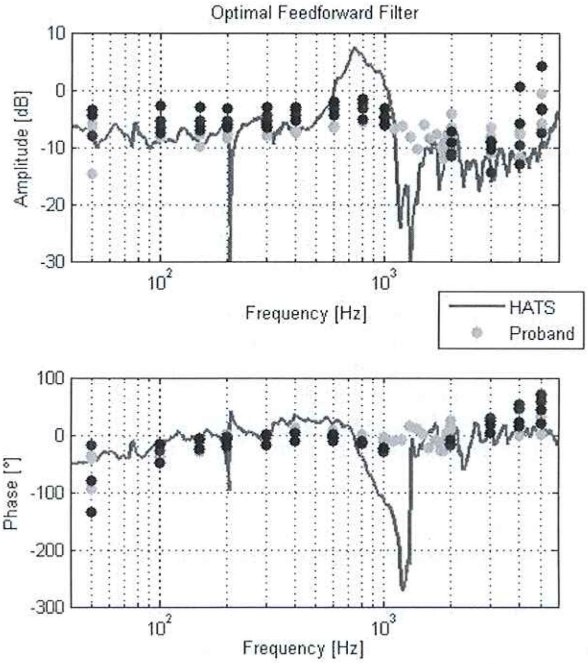

Figure 3: Bode plot of Optimal Feedforward Filter of HATS (line) and Probands (dots), © IMR

2.3 Further Investigations of optimal Filter of humans

Next to the differences of the optimal filter of the humans and the HATS this test also shows inter- and intra-personal differences. Therefore the optimal filter was determined of different probands and also different times for one proband. For this experimental setup the optimal filter under 1000 Hz mainly differed in amplitude by a certain gain. At higher frequencies the optimal values diverge in phase and amplitude. Hence it is not possible to find a static feedforward filter which works in this frequency range at every person. Furthermore only probands where the earphones fitted properly and hence had a good passive dampening had to perform this test. A lose fit results in even more changes of the plants especially in the lower frequency range. To cancel the sound in a wider frequency range or to afford a good attenuation for more people the use of adaptive filter is inevitable.

3 FUTURE WORK

The goal of the following work is to investigate the feedforward filter for In-Ear ANR headphones more detailed. Thereby the first task is to transfer the adaptive feedforward control, which is already proven and tested on supra-aural headsets, to in-ear headsets [3],[4]. Furthermore other control strategies, like they are described in [5] have to be investigated. The aim is to find smart control algorithm which produce a high attenuation with minimal computational demands. To use an adaptive feedforward filter, an extra error microphone inside the ear is needed. It has to be investigated how much this microphone really represents the sound field at the eardrum or how the eardrum can be best approximated.

4 SUMMARY

In fact the head and torso simulator models some acoustic plants of in-ear headphones pretty well and represents there a good average human. However the lack of modeling the passive dampening results in major errors of the optimal filter. Hence for the testing of different filter strategies for in-ear ANR headphones the HATS can not be used in general. The use of probands is inevitable. Furthermore the different optimal filter of the probands show, that to achieve a better attenuation adaptive filters have to be used.

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