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Research on Wireless Earphone System using Multiple Auditory Filters

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ABSTRACT
Digital filters using a typical wireless earphone system are not considered for hearing. In particular, there is a lack of research on auditory-based filter compensation to improve clarity in noise environments. Therefore, it has developed a compensation function for clarity with digital filters based on auditory psychology, away from conventional quantitative noise suppression. It reflects the structural characteristics and environmental conditions of earphones and expects to reduce the auditory load while implementing high clarity.

KEYWORDS: *acoustic control, signal processing, mobile system, electronic control, earphones*

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I. INTRODUCTION

The multimedia listening environment is moving based on mobile devices. Earphones/headphones, which are different from the previous ones, are used, so you can freely hear sounds from outside. However, there are as many factors to consider environmentally as it can be used conveniently outside. In particular, external environmental noise has a masking effect on auditory sensitivity. Therefore, the volume of the earphone is increased to ensure intelligibility, and this brings an excessive burden on the auditory nerve. For this reason, Europe and several countries are trying to relieve the burden on the hearing organs by restricting the volume. However, since the regulation of the overall volume is not an alternative to securing the causal clarity, additional studies on auditory compensation are being sought.

The earphone-based listening environment has different characteristics from the acoustic environment we were used to in the past. In the case of earphones, they flow directly into the half-closed ear canal without going through the space. In this case, since the information on the general acoustic space has been lost, humans perceive it as a completely different sound. If the earphone characteristics that reflect the information of HRTF (Head Related Transfer Function) are not created, the basic conditions for reflecting the acoustic environment are not met. Therefore, the earphone-based listening system must be developed in consideration of these physical structural changes[1].

In this study, a complex mobile wireless earphone system used for multimedia was developed. A filter was developed that reflects the Equal Loudness Contour considering the masking of external environmental noise. In addition, a frequency-specific auditory compensation filter was developed through pure tone auditory testing. These two filters were synthesized through a mobile application and implemented in the form of multiple filters.

II. Main Results

2.1. Auditory compensation filter

Prior research on auditory compensation has been continuously increasing since the 2000s. In particular, BS EN 50332, which limits the output of earphones of mobile devices, is the most representative regulation on hearing management [2]. However, this criterion is not suitable for solving the cause of lack of intelligibility, as only the total volume regulation made by the output of the device and the sensitivity of the earphone is placed.

The "Calibration and Measurement of Reproduction System", which Floyd E. Toole studied, is well known for the study of the sound of space and the perceived sound. Based on this research paper, many researchers are conducting auditory compensation studies for earphone systems[3].

In IEC 60268-7, the most standard technical standard for earphones, the listening environment of earphones is not a complete anechoic environment or a complete reverberation environment, but a complex new environment. This standard indicates that there is no model for integrated auditory compensation yet [4]. However, that does not mean that the need for auditory compensation does not exist. Currently, the auditory compensation curve presented by Olive-Welty's team at AES is considered to be the closest result [5].

Natural acoustic phenomena are based on the propagation of sound through space to auditory organs. However, in the case of earphones, problems arise because they are different from the natural sound transmission path. It skips the transmission space and delivers sound directly to the auditory organs. Therefore, the sound with spatial information compensation is not just a sound of uniform balance, but a natural sound[6].

2.2. Implementing a compensation filter

Basic spatial information is applied to earphone hardware. The anechoic chamber is set up in the standard of ISO 3745. The anechoic chamber is a test facility that can derive a single acoustic characteristic by removing other sound effects other than direct sound[7]. For the HRTF compensation of the hardware, a basic compensation filter was applied to the sample using the Head And Torso Simulator (HATS) in a complete anechoic chamber.

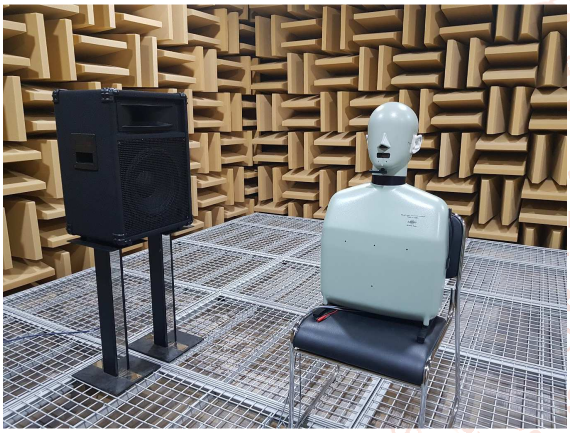

Fig.1. Creating a compensation filter with HATS

Figure 1 shows the calculation of a basic compensation filter applied to a sample using HTAS in a complete anechoic chamber. The frequency response characteristics reflecting environmental information are implemented by referring to the auditory compensation curve. The deleted spatial information is calculated using a simulator having a structure similar to that of the body.

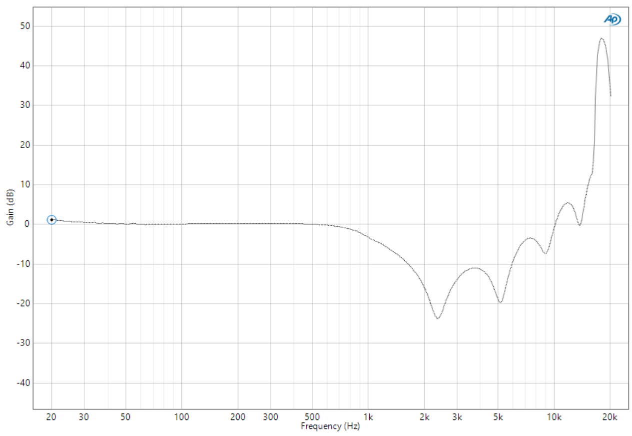

Fig.2. Calculated default compensation filter curve

Figure 2 is a curve graph showing the basic compensation filter calculated through the experiment in frequency units. It is a graph of the result of the basic environmental compensation and is applied directly to the hardware. Filter compensation values are basically applied as characteristic values in frequency units. A high-resolution test is performed for precise measurement, but the scale of 1/3 octave is averaged in consideration of the cognitive characteristics of hearing.

2.3. Mobile application implementation for complex filters

The mobile application system consists of a network server and a smartphone terminal that stores data and applies signals overlaid. The server was developed with python 2.7 and Ubuntu 18.04, and filters can be edited through the admin page implemented through the web.

The mobile system developed in this study implements a hardware-based first-order compensation filter and a software-based second-order compensation filter in combination. The first compensation function is input to the hardware by reflecting the characteristics of the earphone, and the second compensation function superimposes a digital filter in the application of the smartphone. The key to the second-order compensation using a digital filter is to automatically select and apply the filter by detecting the external environmental noise. All DSP modules are interlocked to react actively according to the setting.

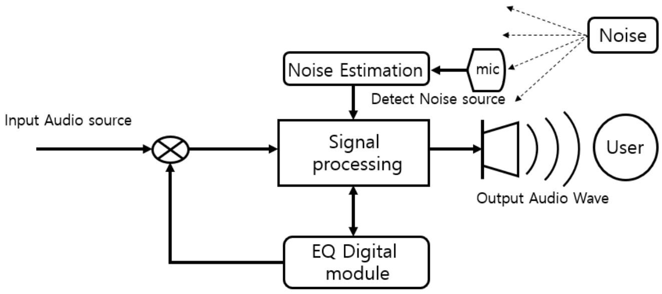

Fig.3. Structural diagram of environment compensation filter implementation

In order to implement an environmental compensation filter that detects external environmental noise, input/output is controlled in the structure shown in Figure 3. In order to analyze the input of noise, the input signal of the microphone mounted on the smartphone is calibrated according to the sound pressure level through a measurement experiment. The corrected sound pressure detects the amount of noise introduced from the external environment and automatically selects a compensation filter according to the previously input matching table.

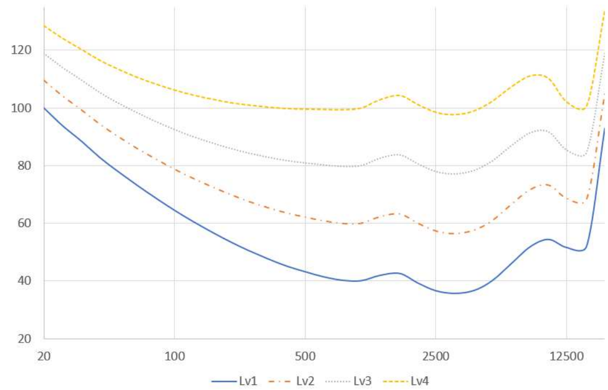

Fig.4. Equal loudness contour ISO226 :2003

Figure 4 shows the criteria of the compensation filter connected to the environment detection matching table. It is the value of the Equal Loudness Contour curve of the standard standard corresponding to ISO 226. The equalizer is input in consideration of the masking level recommended in IEC 60268-5[8].

2.4. Characteristic result calculation and MOS test

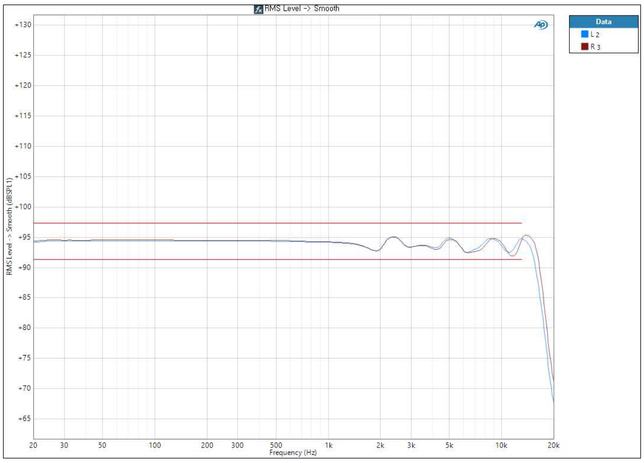

Fig.5. Frequency response characteristics of a sample with rewarding characteristics

Figure 5 is the result of measuring the frequency characteristics of hardware to which the first-order compensation is applied. The measurement results aimed to achieve a linear characteristic from 20 Hz to 13 kHz. The target range was set within the range of ± 3 dB, which can be referred to as a general tolerance, and it was confirmed that the measured sample was within the target range.

Table 1. Speech clarity evaluation

Type of test	Test result	
	Condition	Total Mean Opinion Score
Listening evaluation	Listening Evaluation Committee 10	4.79

Table 1 is the result of evaluating the clarity of the mobile system. The evaluation was conducted through a panel of 10 selected listening evaluation committees. Comprehensive intelligibility and listening performance were scored with Mean Opinion Score (MOS). The evaluation was conducted in accordance with the listening evaluation technology standard of KS C IEC 60268-13 [9].

The MOS test is a scoring system defined in ITU-T Recommendation P.800 (Methods for subjective determination of transmission quality, 1996). The grade of the score is divided into 5 levels: 5 (Excellent), 4 (Good), 3 (Fair), 2 (Poor), and 1 (Bad), and scores of 4 or more are determined as high quality[10]. The evaluation result was an overall score of 4.79, which was evaluated to be effective in improving clarity overall.

III. Conclusion

In this paper, we developed a wireless earphone system applying multiple filters. The feature is that it is a complex system that compensates for both hardware-based earphone characteristics and software-based frequency characteristics, not through compensation through an increase in overall sound pressure. Considering the limited condition of earphone, it was reflected in the hardware, and an automatic filter that reflected the external environment could be applied through a smartphone application. Based on the wireless earphone, the user's listening environment can be improved by simultaneously applying active effects such as auditory compensation and environmental response. Therefore, it is not necessary to increase the overall volume to compensate for the intelligibility, and to avoid excessive load on the hearing, and it is possible to apply an optimized setting for each user.

We are preparing further research on improving speech recognition intelligibility, which is optimized for the next study. We plan to develop a more suitable environmental compensation filter by using AI to calculate a compensation filter for the spatial environment.

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