24th INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
23–27 July 2017, London

OBJECTIVE EVALUATION OF THE SOUND QUALITY FOR ACCELERATING WARNING SOUND OF ELECTRIC VEHICLE BASED ON WHINE INDEX

Manuk Han and Sang-Kwon Lee

Inha University, Department of Mechanical Engineering, Incheon, Republic of Korea
email: nanoneo@naver.com

Electric Vehicle(EV) generate sound pressure lower than internal combustion engines(ICE) vehicle at low speeds. Pedestrians familiar with internal combustion engines find it difficult to recognise such quiet vehicles. Therefore, an additional warning sound generator is required. The warning sound must have high detectability and low annoyance to pedestrians, while complying with legislation for warning sound of country. In this paper, EV warning sounds were made based on previous research result. The AM signal is more suitable as an EV warning sound than the FM signal. As the frequency rises as the rpm of the ICE vehicle increases, the EV warning sounds were designed so that the frequency changes depending on the speed. In previous research, AI(Annoyance Index) and DI(Detectability Index) of the electric vehicle warning sound were obtained with a consideration of the masking effect. Two index were calculated and judged to be appropriate as a warning sound.
Keywords: electric vehicle, warning sound, whine index, annoyance, detectability

1. Introduction

Most automakers have tried to reduce the noise of vehicles. But electric vehicles(EV) are the opposite. Due to the characteristics of the electric motor, it is as low as 6dB(A) at 10km/h[1]. This difference is reduced by tire noise at around 40km/h. This little noise has become a potential risk for pedestrians familiar with internal combustion engine vehicle noise. According to statistical surveys, although the sales level of electric vehicles was low at the time of the survey, accidents caused by EV of pedestrians or cyclists were reported to be seriously high[2]. Now a variety of studies have been conducted to develop EV warning sound. In previous research, partial loudness has been correlated with the annoyance of the warning sound. However, the partial loudness due to the background noise is not correlated[3]. In another research, the amplitude envelope of a signal is said to be related to perception. In the case of small fluctuating frequencies, it is said that the effects of perception depend on the model of the envelope[4]. However, EV warning sound at depending on the speed has not been studied yet.

In this paper, EV warning sound depending on the speed is developed. Using the index obtained in the previous study, the suitability of the designed sound was evaluated in terms of perception and irritability. Fundamental frequency equation is set, and this equation is assigned to real number to make eleven different signals, and synthesized into one signal. The sound pressure was set depending on the speed from 5km/h to 30km/h. This paper is organized as follows. In section 2, EV warning sound depending on the speed was developed. In section 3, the generated signal is evaluated through the index developed in the previous study. Section 4 describes the conclusions of this study.

2. Stimuli

2.1 Design EV Warning Sound

The frequency of noise generated in an internal combustion engine vehicle depends on RPM. This frequency also appears as an integer or half order. Similarly, the warning sound was composed of eleven different AM signals obtained by multiplying the fundamental frequency equation by a real number. In this paper, the fundamental frequency equation is defined as 1 order. 1 order starts at 170Hz and increases linearly to 340Hz. There is a previous study that AM signals are more suitable than FM as a warning sound in EV[5]. Five of the eleven signals represent the main sound of the warning sound, and the each order has a different sound level. Fig. 1 is a STFT(Short Time Fourier Transform) result of some of the designed signals. Through the STFT, the frequency and sound pressure information of the signal over time can be known.

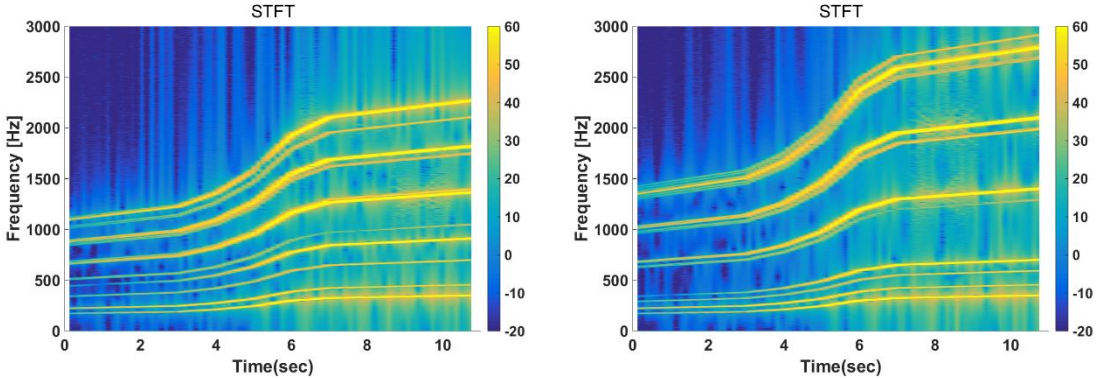

Figure 1: STFT(Short Time Fourier Transform) among the designed signals.

EV warning sound are designed to comply with NHTSA(National Highway Traffic Safety Administration) regulation. The following are the requirements of the NHTSA. The frequency band between 160Hz and 5000Hz should be used. Depending on the speed of drive, sound levels above 49dB(A) at idle, 55dB(A) at 10km/h, 62dB(A) at 20km/h and 66dB(A) at 30km/h should be generated[6]. Considering the masking effect due to the background noise, it was adjusted by 10dB(A) higher than the level proposed by the NHTSA.

2.2 Noise

Background noise is recorded on an actual road, and the influence of ambient background noise is considered. Background noise consists of the following three. The dry noise recorded during a clear weather afternoon, the wet noise recorded during a rainy afternoon, and the white Gaussian noise with the middle value of two other background noises. Except for the white noise, two background noises are recorded along with the passing sound of the actual vehicles, so as to determine how effective the warning sound is.

2.3 Synthesize

All total of 30 signals were obtained by synthesizing ten warning sound and three background noises. In the next section, AI(Annoyance Index) and DI(Detectability Index) are calculated to find a suitable signal as warning sound.

3. Index Calculation

In previous research, whine sounds masked by background noise were extracted using masking theory and whine index of new sound quality elements were developed[7]. Detectability Index(DI) and annoyance index(AI) were developed through a high correlation between the subjective evaluation of perception and irritability and the objective whine index value. Two indices were calculated for the synthesized 30 signals.

3.1 Annoyance Index and Detectability Index

Fig. 2 shows the horizontal and vertical axes of the AI and DI results for 30 signal. Signals with high cognitive and low irritability are different depending on the background noise. When judged synthetically, number 3 and 7 signals are the best, and 6 and 8 signals are the worst.

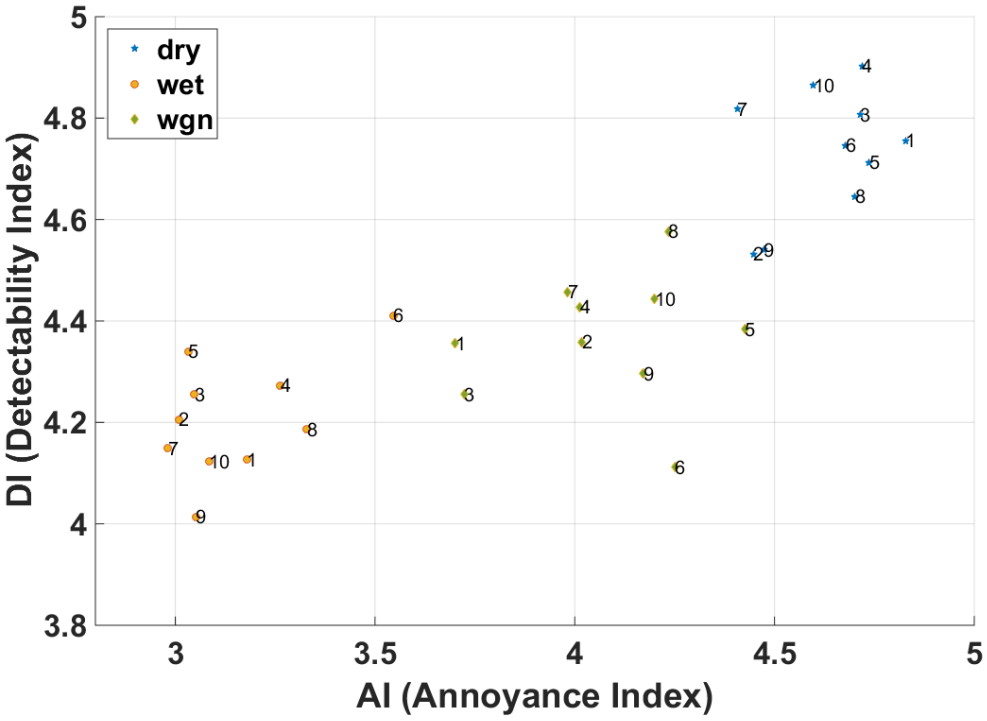

Figure 2: 2-Dimensional plot of synthesized signals.

4. Conclusion

In this paper, EV warning sounds were designed depending on the speed and synthesize three background noises. For a total of 30 signals, the index was calculated using the results of previous studies. A suitable signal was selected as an EV warning sound that can convey high perception and low irritability to pedestrians.

5. Acknowledgement

This work was supported by Mid-career Researcher Program through NRF of Korea grant funded by the MEST (No. 2015R1A2A1A15052549).

REFERENCES

1 Zeitler, A. Psychoacoustic Requirements for Warning Sounds of Quiet Cars, *SAE Int. J. Passeng. Cars – Electron. Electr. Syst.* **5**(2), 572-578, doi:10.4271/2012-01-1522, (2012).

2 Hanna, R. Incidence of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles, *National Highway Traffic Safety Administration(NHTSA)*, DOT HS 811 204, (2009).

3 Jacobsen, G. N., Ih, J. G., Song, W. K. and Macdonald, E. N. Predicting Detectability and Annoyance of EV Warning Sounds Using Partial Loudness, *Proceedings of the 45th International Congress on Inter-noise*, Hamburg, Germany, 21-24 August, (2016)

4 Yasui, N. and Miura, M Effect of amplitude envelope on detectability of warning sound for quiet vehicle, *Proceedings of the 45th International Congress on Internoise*, Hamburg, Germany, 21-24 August, (2016)

5 Parizet, E., Ellermeier, W. and Robart, R. Auditory warnings for electric vehicles: Detectability in normal-vision and visually-impaired listeners, *Applied Acoustics*, **86**, 50-58, (2014)

6 Garay-Vega, L., Hastings, A., Pollard, J. K., Zuschlag, M. and Stearns, M. D. Quieter cars and the safety of blind pedestrians: Phase I, *National Highway Traffic Safety Administration(NHTSA)*, DOT HS 811 304, (2010).

7 Lee, S. K., Lee, S. M. and Han, M. U. Objective Evaluation of Sound Quality in An Electric Vehicle Based on Effect of Temporal and Spectral Masking, *Proceedings of the 36th International Federation of Automotive Engineering Societies(FISITA)*, Busan, South Korea, 26-30 September, (2016).