Development of a Railway Noise Evaluation System Using Virtual Reality Technology

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Abstract:

The evaluation of railway noise is very important for planning and designing of new line and investigation of sound isolation in urban area. In the conventional studies, the computed noise level is visualized using computer graphics such as iso-surface. Although the visualization is a powerful tool to understand the distribution of noise, it is difficult to recognize the noise level intuitively.

This paper presents a railway noise evaluation system using virtual reality technology. The simulation of noise level is performed by using the geometric acoustic theory. In order to recognize stereo sound field, we introduced the ambisonics based on the spherical surface function expansion to realize the stereoscopic sound field. In order to consider the train car composition, we used the sound source data which is classified into motor car and non-motor car. The computed results are compared with the measurement data in both real space and virtual reality space. The present system is shown to be a useful tool for planning and designing tool for railway environments.

Keywords: VR technology, Geometrical Acoustic Theory, Railway Noise.

1. INTRODUCTION

Noise causes sensual and psychological damage such as hearing loss, headache, gastrointestinal disorder. It is important to predict the influence of noise in the railway projects, as it is one of the big social problems. In railway projects, for construction of new lines, elevated bridge, soundproofing, etc. are carried out, it is important to predict and evaluate the noise levels. Numerical analysis has been widely used as a prediction and evaluation method of noise level due to the dramatic development of computer performance in recent years (Thompson, 2008). A number of evaluation methods for noise simulation have been presented. Based on the frame of reference used, those methods can be classified into two categories: 1) Methods based on the geometrical acoustic theory (The Acoustical Society of Japan, 2009) and 2) Methods based on the acoustic wave theory. Both methods have advantages and disadvantages (Architectural Institute of Japan, 2011). For the methods based on the geometrical acoustic theory, the CPU time is short but the numerical accuracy is low comparing with the methods based on the acoustic wave theory. On the other hand, the methods based on the acoustic wave theory give accurate solutions but the scale of simulation becomes large.

Having considered the road traffic and aircraft noise and VR (virtual reality) technology which has been remarkably developed and popularized for a few years, we have constructed a noise evaluation system that presents the simulation results as auditory information in real time (Ishida et al, 2016; Shibata et al, 2010; Tajika et al, 2009). The authors combine geometric acoustic theory which can calculate large scale space in real time. The feature of this system is that a realistic pseudo experience can be gained by presenting noise from both visual and auditory aspects. Meanwhile, the noise levels are calculated in real time using the position information of the user in the VR space, and by making the noise level audible using actual noise source data together with CG images of moving automobiles and aircraft.

Therefore, in this paper, we develop a railway noise evaluation system using virtual reality technology based on the above-mentioned system. Also, so as to consider the train car composition, the sound source data was classified as a motor car and a non-motor car. In order to verify this method, we compare the numerical result with the actual observation result and the measurement results in VR space.

2. RAILWAY NOISE EVALUATION SYSTEM

2.1 System Environment

Fig.1 shows the VR system “HoloStage” of Chuo University. This system is composed of three large and flat screens and high-performance projectors corresponding to the screen and wireless tracking devices for capturing the movement of the user in the VR space, and a parallel computer for controlling them. The computer environment consists of one Master-PC for control and four Slave-PCs. One of the four Slave-PCs is to track and capture the position of the marker attached to active shutter glasses and the controller used by the system user in real time.
Fig. 2 shows active shutter glasses and controller. The other three Slave-PCs are for the projector and are connected to the projector, and create images of the each screen. This system also has an audio system with 7.1ch speakers. These make it possible to experience audible results with immersive feeling.

Figure 1. VR system “HoloStage”  
Figure 2. Device

2.2 System Overview

Fig. 3 shows the flowchart of the railway noise evaluation system. The system consists of a visualization part and an auralization part. First, simulation conditions such as the traveling conditions of the train and the sound power level of the sound source are determined. Then, in each time loop, the position coordinates of the sound source position are calculated, and the position information of the observer which is located at the sound receiving point in the VR space is acquired by the tracking device. For the visualization part, the Open GL and CAVE library are employed for the preparation of CG image. For the auralization part, the construction of stereoscopic sound field is achieved by the method based on “ambisonics” (Ward & Abhayapala, 2001), which is a full-sphere surround sound technique based on the spherical function expansion.

![Flowchart of this system](image)

Figure 3. Flowchart of this system
3. CREATING NOISE SOURCE DATA

3.1 Railway Noise

Railway noise can be classified into two categories; 1) noise from moving train such as rolling noise, aerodynamic noise, motor, and so on (hereinafter, referred to as traveling noise), 2) noise from joint of rail which is the impact noise by the passing of wheel (hereinafter, referred to as impact noise) (Ishii et al. 1980; Moritoh et al. 1996). In this paper, the steady state noise prepared by measuring traveling noise and impact noise using a sound level meter is implemented in the VR system. Both were done at a distance of 9 m from the center of the rail.

3.2 Measurement of Traveling Noise and Impact Noise

The noise source data was measured at the Minami-Furuya Station JR (Japan Railway) Kawagoe Line (Kawagoe city, Saitama Prefecture). Measurement of traveling noise was carried out far enough away from the joint of the rail at a point where there is no influence of impact noise. Measurement of impact noise was done at the joint of the rail. Meanwhile, the speed of the train was assumed to be 83 km/h.

To calculate high precision and audible sound more realistic, noise source data for auditioning was created for various types of train cars. Specifically, the traveling noise is treated as each traveling noise by distinguishing between a motor car and a non-motor car. Fig. 4 shows the train car composition of Kawagoe Line on which the traveling noise was measured, and the waveform of the sound pressure when the train passed. The red circles in the figure indicate the position of the bogie. A steady state noise was created using the corresponding parts of the motor car and the non-motor car respectively, among the data shown in the figure. The inside of the red frame is the noise source data used for the steady state of the motor car, and the inside of the purple frame is the noise source data used for the steady state of the non-motor car.

Fig. 5 shows the waveform of sound pressure when the train was passing through the rail joint. In the figure, an impulsive rising waveform of the sound pressure is seen at a constant cycle, which represents the striking sound generated when the wheels of the railroad pass through the joint of the rail. The inside of the red frame in the figure is the noise source data implemented as the impact noise.

3.3 Create Steady State Noise Data of Traveling Noise

Fig. 6 shows the process of creating a steady state noise for a motor car. The red frame corresponding to the motor car in Fig. 6(a) is not suitable for repeatedly producing sound data because it contains the non-stationarity associated with traveling. Therefore, as shown in Fig. 6(b), the noise source data which is repeated within the red frame was synthesized by shifting the phase by 1/3 each, so that a steady state noise equivalent to the traveling noise was created as shown in Fig. 6(c).
Fig. 7 shows the comparison of the power spectra for every frequency between measurement noise data and steady state data for motor cars and non-motor car. "M" in the figure indicates the position of the motor car. It is found from the figure that both the power spectra match with each other and that the steady state noise is created without affecting the frequency characteristics. In the low frequency range, it is confirmed that the sound power level of the motor car is larger than that of the non-motor car and the frequency characteristics are different.

![Figure 6](image6.png)

**Figure 6. Process of creating a steady state noise**

![Figure 7](image7.png)

**Figure 7. Comparison of the power spectra**

### 4. ACOUSTIC CALCULATION

In this paper, the ASJ RTN-Model 2008 which treats sound source as a point sound source in a semi-free-field was used for calculation of traveling noise and impact noise (Architectural Institute of Japan, 2011). The steady state noise created for each train car as traveling noise are arranged at the center of each bogie corresponding to motor cars and non-motor cars, and are treated as a point sound source moving with each train car. Also, the impact noise is placed on the joint of the railway track, and the sound is generated at the moment when the bogie of the train car model passes. Fig. 8 shows the layout of traveling noise and impact noise. It is known that the traveling noise of a train has bidirectionality, on which noises are difficult to propagate on the traveling line and easily propagate in the lateral direction (Kaite, 2010). It is treated as a point sound source having bidirectionality as shown in Fig. 9.
The sound pressure level at the observation point generated from each sound source is defined by the following equation.

\[ L_A = L_{WA} - 8 - 20 \log_{10} r + 10 \log_{10} \cos^n \theta \]  

(1)

where

- \( L_A \): sound pressure level,
- \( L_{WA} \): sound power level at the sound source point,
- \( r \): distance from bogie to observation point,
- \( \theta \): an angle between normal direction and wave direction.

Fig. 8. Layout of traveling noise and impact noise

Fig. 9. Directional model

The sound pressure level at the observation point is the sum of Eq. (1), which is a propagating sound from each sound source, and is defined by the following equation.

\[ L_A = 10 \log_{10} \sum (10^{L_{Ai}/10}) \]  

(2)

where

- \( i \): number of sound sources

Fig. 10 shows the positional relationship between the traveling noise and the observation point. The length of the observed train car is 20 m, and the distance from the center of the bogie to the edge of the train car is 2.9 m. The sound power levels of motor car and non-motor car were calculated to be 107 dB and 103 dB, respectively, from the actual measurement results.

Fig. 10. Positional relationship between the traveling noise and the observation point
5. VISUALIZATION AND AURALIZATION

This is a system that the user can experience the sound simulation from both the visualization and auralization by using the image of the moving train and the sound pressure level calculated in real time.

5.1 Visualization

In this paper, the terrain model around the Minami-Furuya station and the train model are created using 3D CG modeling software, and are projected to the VR space. The observation point is shown in Fig. 11, and the terrain model created in Fig. 12.

Figure 11. Measurement area

Figure 12. Terrain model created

5.2 Auralization

The 3D acoustic field is constructed by a 7.1 channel speaker system of the VR system. Output of traveling noise and impact noise is performed by calculating sound pressure levels and position coordinates of sound source by using C++ program and control of speaker using Max (a visual programming language). Traveling noise is reproduced by repeatedly playing the created steady state noise. The impact noise is reproduced by playing the impact noise data only once at the moment each bogie passes through the rail joint. The sound pressure level at the observation point calculated by C++ is transmitted to Max using OSC (Open Sound Control), and the sound is output from the speaker based on the volume. The 3D acoustic field can be created by the Ambisonics (Ward and Abhayapala, 2001) technique. Ambisonics is based on the spherical surface expansion, using computational results and sound data.

6. APPLICATION EXAMPLE

In order to examine validity and effectiveness of this method, we compare the calculation results in this method with measurement results, and investigate the reproducibility of auditory results in the VR space. In order to make the simulation conditions the same as the actual conditions, in the VR space, the train speed was set at 83 km/h and the distance between the observation point and the center of the rail was set to 9 m as shown in Fig. 13.

Figure 13. Measurement in VR space
Fig. 14 shows comparisons between calculation results and measurement results. It can be seen that the calculation result considering train car composition shows good agreement with measurement result. On the other hand, the calculation results without the train car composition do not agree with the measurement result.

Fig. 15 shows the comparison between the calculation result in this method and the measurement result in the VR space. The measurement result in the VR space shows a good agreement with the calculation result, and so it is be confirmed that the auralization is correctly performed. Differences appearing before and after passing through the train are possibly attributed to reverberation and background noise.
7. CONCLUSIONS

In this paper, we have constructed a railway noise evaluation system using virtual reality technology. Also, so as to consider the train car composition, the sound source data was classified as two sources from a motor car or a non-motor car.

To validate this method, we compare the calculation results with the actual observation results and with the measurement results in VR space. As a result, the following conclusions are obtained.

First, the calculation results by this method show good agreement with the actual measurement results. Calculation accuracy was improved by considering the train car composition, and therefore making it possible to experience railway noise with higher quality.

Second, the calculation results by this method also show good agreement with the measurement results in the VR space. It implies that the sound field was reproduced in terms of high fidelity in the VR space.

As future research topics, we plan to investigate transplantation of this system to HMD (Head Mounted Display) type VR device, and to consider aerodynamic noise for high-speed train such as Shinkansen, and to implement various structural noises such as bridges.

REFERENCES


