A Road Traffic Noise Evaluation System Considering A Stereoscopic Sound Field UsingVirtual Reality Technology

***Kou Ejima[1], Kazuo Kashiyama[1], Masaki Tanigawa[2] and Masayuki Shimura[3]**

[1]Department of Civil and Environmental Engineering, Chuo University, Japan
[2]Deputy Senior Research Engineer, Shimizu Corporation, Japan
[3]General Engineer, Civil Engineering and Eco-Technology Consultants, Japan

*Corresponding author: ejima@civil.chuo-u.ac.jp

Abstract

This paper presents a road traffic noise evaluation system based on spatialization of sound using virtual reality technology. The key feature of the system is that the road traffic noise is provided for users by both audio and visual information under various road and vehicle conditions. The geometric acoustic theory is employed for the simulation of traffic noise to realize the real-time simulation. In order to improve the reality, the sound source data for the auralization in VR space are generated from the various car driving tests. This system is applied to several examples in order to investigate the validity of the method.

Keywords: Geometric acoustic theory, Road traffic noise, Stereoscopic sound field, Virtual reality

Introduction

The evaluation of road traffic noise is very important for planning and designing of road environment, because the road traffic noise infect the human body such as disruption of sleep and psychological malaise and so on. There have been presented a number of numerical simulation methods in accordance with the development of computer. The theory for numerical simulation can be classified into two approaches; wave acoustic theory and geometric acoustic theory. The geometric acoustic theory is very useful for the development of the real time simulation system because the computational time is much shorter than the wave acoustic theory.

Generally, the numerical results are visualized using computer graphics (CG). However it is difficult to understand the noise level intuitively with CG, because the visualization is not auditory information. In order to overcome the problem, several systems that expose road traffic noise as the auditory information have been presented in the past studies (Nagano et al. (1999), Makanae et al. (2004)). However, there have not been presented a system that presents auditory and visual information simultaneously under the various road environments. The present author developed a system to expose the numerical results both with auditory and visual information using virtual reality (VR) technology (Tajika et al. (2010), Shibata et al. (2011)). The ASJ RTN-Model 2008, which is the Japanese standard model for road traffic noise, was employed for the model based on the geometric acoustic theory. The system was designed as an interactive system which realizes the real time simulation. However, the following problems are pointed out from the point of the reality of our system; 1) The effects of directivity of the sound wave and delay of the arrival time are not considered. 2) The sound source of the vehicle in the system is not related to the vehicle type and speed.

This paper presents an advanced road traffic noise evaluation system that can overcome above mentioned problems. In order to consider the effects of directivity of the sound wave and delay of the arrival time, we realize stereoscopic sound field in VR space. Furthermore, the sound source data for the auralization in VR space is generated from the various vehicle driving test.

VR Environments

The IPT (Immersive Projection Technology) is employed for VR technology. Fig.1 shows the VR system “HoloStage” of Chuo University, Japan. This system is composed of three large and flat screens and three high-performance projectors corresponding to the screen. The front and side screens are transmissive ones and the bottom screen is reflective one. The projector shows the CG image for left and right eyes alternatively with 120Hz. Users wears the shutter glasses (Fig.2 (a)), which will open and close the shutter with the synchronization to the CG image through infrared emitters . Users can move the arbitrary position using the controller (Fig.2 (b)). This system has 7.1ch sound speakers (Fig.2 (c)) and the VR space is created by the auditory information and the visual information. Observer's motion is captured by a system called VICON Tracking system (Fig.2 (d)), which is the optics type motion tracking system. The positions of makers fitted to shutter glasses and controller are tracked by the tracking system.

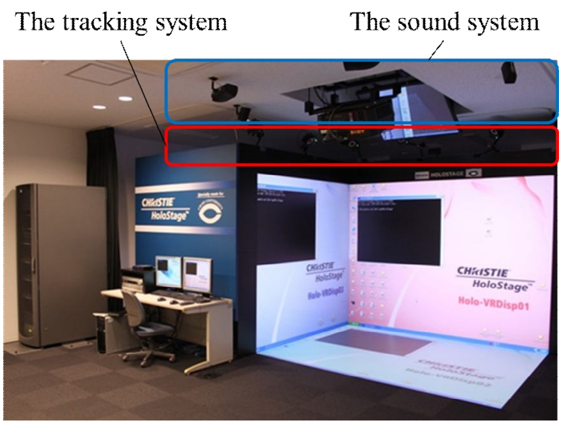


Figure 1. VR system (Holostage)

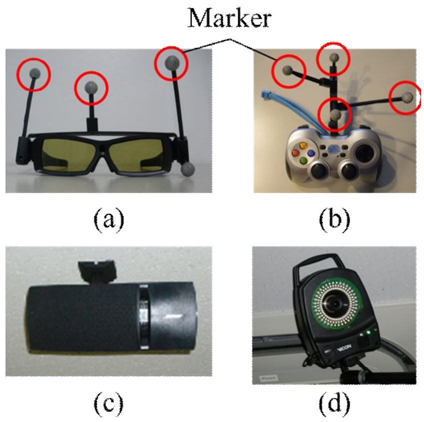


Figure 2. The device of VR system

A Road Traffic Noise Evaluation System Using VR Technology

The interactive road traffic noise evaluation method is designed for the use of CAVE environments based on the immersive projection technology (IPT). The auditory information of road traffic noise is created using the MAX (Cycling'74). Fig.3 shows the concept of the system. This system provides two presentation methods for computed road traffic noise level, a) auralization function, which presents the auditory information of the road traffic noise based on numerical results with the stereoscopic animation of vehicle run (Fig.3 left), and b) visualization function, which presents the stereoscopic iso-surface of the road traffic noise level by CG image with the road environment's CG (Fig.3 right). Users can easily understand how big the noise of the simulation results using the auralization function. On the other hand, users can easily understand the spatial distribution on the noise level using the visualization function.

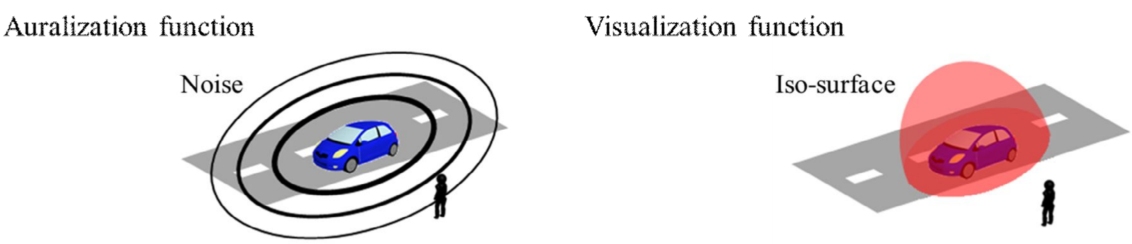


Figure 3. The concept of the system

The present system provides following three characteristics. First, users can move to arbitrary position and can hear the road traffic noise that correspond with the position, since the road traffic noise level is computed in real time using the position of user (Fig.4 (a)). Second, users can change the road environment; height of noise barrier, pavement type (drainage pavement and dense pavement) and passage years after pavement (Fig.4 (b)). Third, users can change the vehicle conditions; vehicle type, vehicle speed and running distance of vehicle (Fig.4 (c)). Fig.5 shows the available road environments for the simulation in this system. Table 1 shows the input data in case of the road environment with noise barrier and users can set the data using the interface function which is displayed on the front screen as shown in Fig.6. Fig.7 shows computational result when building is set.

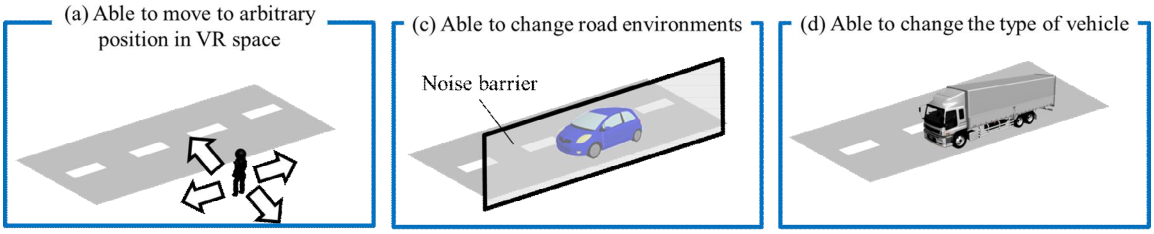


Figure 4. The overview of the system

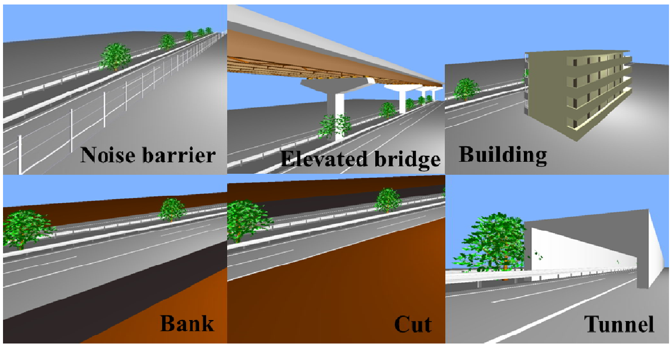


Figure 5. Surrounding road environments

Table 1. Input data

The height of sound barrier	0 ～ 5m
Type of vehicle	Standard, Subcompact, Middle, Large car and Bike
Vehicle velocity	50 ～ 100km/h (interval :10km/h)
Type of the pavement	Drainage and dense-graded pavement
The passage years of pavement	0 ～ 15years (interval:5years)

Figure 6. Interface function

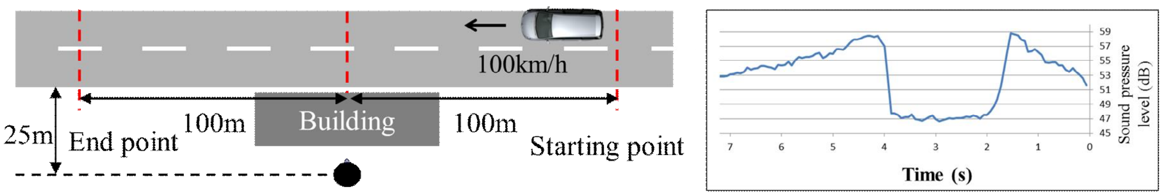


Figure 7. Computational result

Computation of road traffic noise level

The road traffic noise level is computed by using the ASJ RTN-Model 2008 (The Acoustic Society of Japan (2009)). The sound pressure level is evaluated in real time by the model, since the model is based on the geometric acoustic theory.

The computation is performed using the position data of the vehicle, the observer, and the surrounding environment in real time using a motion tracking system. Fig.8 shows the sound propagation with sound barriers. The A-weighted sound power level of vehicle noise L_{WA} can be expressed as:

$$L_{WA} = a + b\log_{10} V + C \tag{1}$$

where a is the factor related to the types of vehicle (the values for standard car, bike, subcompact car, middle car and large car are assumed to be 46.7, 47.6, 51.5, 44.4, 49.6, respectively), b is the coefficient relate to the vehicle speed, V is the vehicle speed, C is the correction term (the noise reduction with drainage pavement etc, the change of road vehicle noise by the vertical slope, the directivity of vehicle noise).

The A-weighted sound pressure level L_A of direct sound which is propagation from vehicles is evaluated as:

$$L_A = L_{WA} - 8 - 20\log_{10} r + \Delta L_{cor} \tag{2}$$

where r is the distance in a straight line between observer and vehicle, ΔL_{cor} is the correction concerning with attenuation factors (attenuation caused by diffraction, grand effect and atmospheric absorption).

When it is necessary to consider about the plural propagations such as direct sound, reflection and diffraction sounds, the A-weighted sound pressure level is computed as:

$$L_A = 10\log\left(\sum_{i=0}^{i_{\max}} 10^{\frac{L_{A,i}}{10}}\right) \tag{3}$$

where $i_{\max}$ is the number of the sound propagations, $L_{A,i}$ is the sound pressure level corresponding the sound propagation. The Doppler effect is also considered in this system.

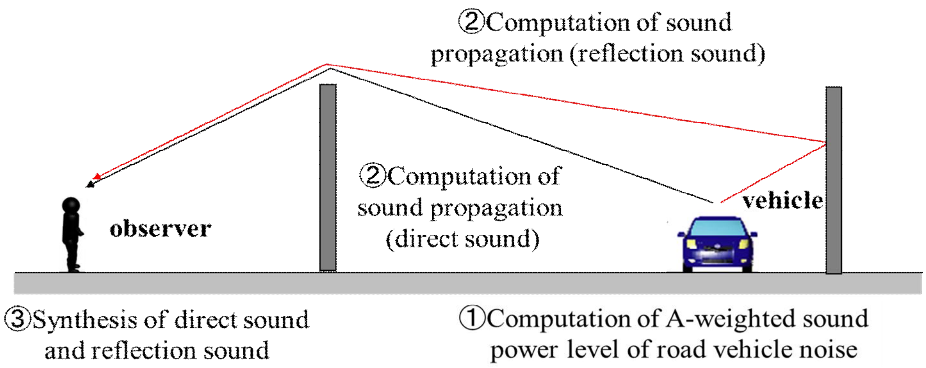


Figure 8. Sound Propagation by ASJ RTN-Model 2008

Development of Stereoscopic Sound System

In order to improve the presence of auralization function, the spacialization of sound field is achieved. The system consists of two parts; visualization and auralization parts as shown in Fig.9. The sound source data is obtained from the various vehicle driving test which is explained in the next section. The Open Sound Control (OSC) which is UDP/IP protocol is used for the data communication. The spatialization of sound is achieved by the method named "ambisonics" (Ward, 2001, Tanigawa et al. (2013)), which is based on the spherical surface function expansion, using computational results and sound source data. For the preparation of CG image, the Open GL and CAVE library are employed and the Max is employed for the specialization of sound.

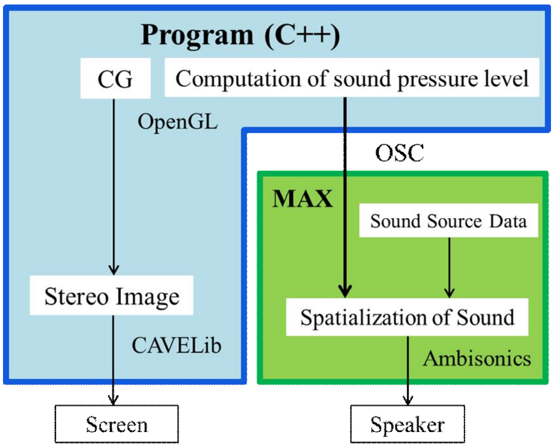


Figure 9. Flowchart of the stereoscopic sound system

Implementation of the Sound Source Data

Observation of road traffic noise

In order to obtain the sound source data for the road traffic noise, the observation of driving sound for various type of vehicle is performed at The National Institute for Land and Infrastructure Management, Tsukuba, Japan. Fig.10 shows the type of vehicles which are used for the observation. The sound is observed by the noise level meter which is set to the fixed point as shown in Fig.11. The vehicle speed is changed from 50km/h to 100km/h with the constant interval 10km/h. The sampling frequency of the noise level meter is assumed to be 20kHz.

Fig.12 (a) shows the observed waveform in case for the standard car 90km/h. In this figure, the maximum sound pressure is normalized as 1.0 and the time when the vehicle pass through the front of the noise level meter is assumed to be 0 sec. From this figure, it can be seen that the sound pressure involves the distance attenuation clearly.

a) Standard car b) High-powered bike c) Small truck (2t)

d) Medium truck (4t) d) Large truck (10t)

Figure 10. Type of vehicle in driving tests

Generation of sound source data for auralization

In order to generate the sound source data for auralization from the measured data, it is necessary to remove the effects of the distance attenuation using the geometrical relation as shown in Fig.10. In this figure, T_1 is the actual elapsed time, T_1' is the elapsed time considering the sound speed (time at observation point), S is the sound pressure at vehicle and S' is the sound pressure at observation point. The sound pressure $S'(T_1')$ can be expressed by the following equation considering the distance attenuation.

$$S'(T_1') = \frac{1}{R(T_1)} \cdot S(T_1) + \alpha \tag{4}$$

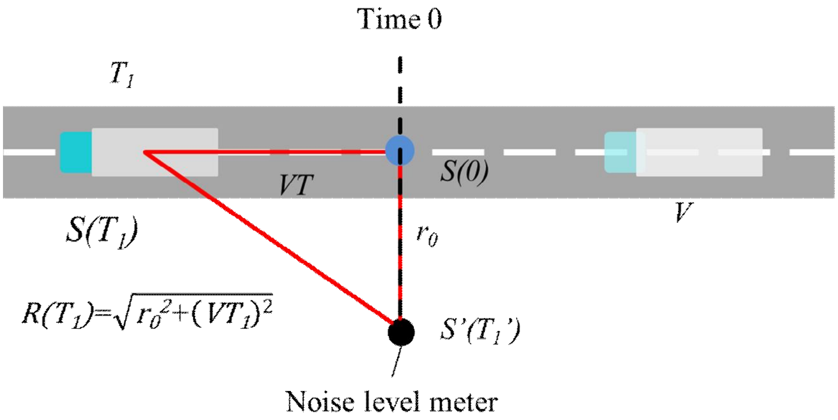


Figure 11. Measurement of vehicle noise

where $R(T_1)(=\sqrt{r_0^2 + (VT_1)^2})$ denotes the horizontal distance between observer and vehicle, and α denotes other sounds such as reflected sound and background noise, and which is assumed to be 0.

Time T_1' is expressed by the following equation.

$$T_1' = T_1 + \frac{R(T_1)}{c_0} \tag{5}$$

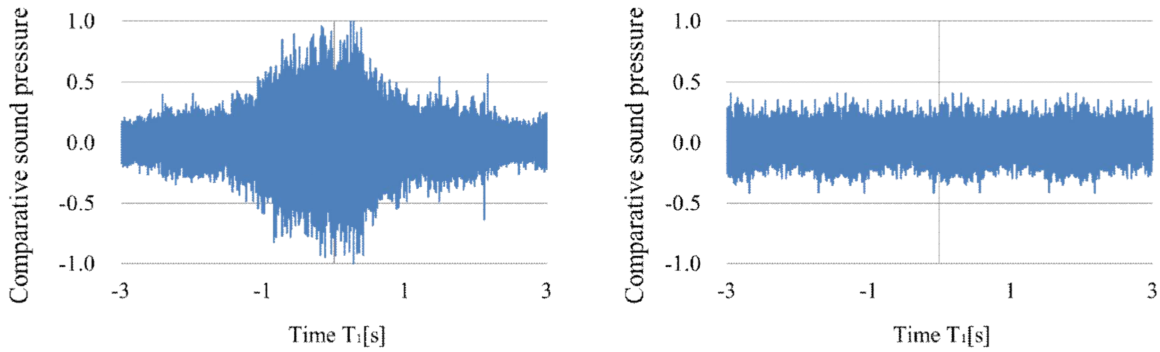
where, c_0 is acoustic velocity. From Eq. (4) and (5), the time T_1 can be expressed as:

$$T_1 = \frac{2T_1' + \sqrt{4T_1'^2 - 4(1-M_0^2)(T_1'^2 - Q_0^2)}}{2(1-M_0^2)} = F(T_1') \tag{6}$$

where, variable of M_0 and Q_0 is V/c_0 and r_0/c_0. Therefore, the sound pressure at the vehicle $S(T_1)$ can be evaluated by following equation as the function of T_1'.

$$S(F(T_1')) = \beta(T_1')S'(T_1') \tag{7}$$

where $\beta(T_1')$ is the correction coefficient which can be written as $R(F(T_1'))$. Fig.12 (b) shows the sound source data which is used for the auralization of the road traffic noise system. From this figure, it can be seen that the effects of the distance attenuation is removed. Fig.13 shows the comparison of power spectrum in case that the both sound at 1000Hz are assumed as 0dB. It can be seen that both power spectrums coincide with each other. Fig.14 shows the comparison of power spectrum for various type of vehicle in case that the speed of vehicle is 100km/h. From this figure, the power spectrum of large truck and bike are big in the range of low frequency comparing with others.



(a) Measured data $S'(T_1')$ (b) Generated data $S(F(T_1'))$

Figure 12. Generation of sound source data

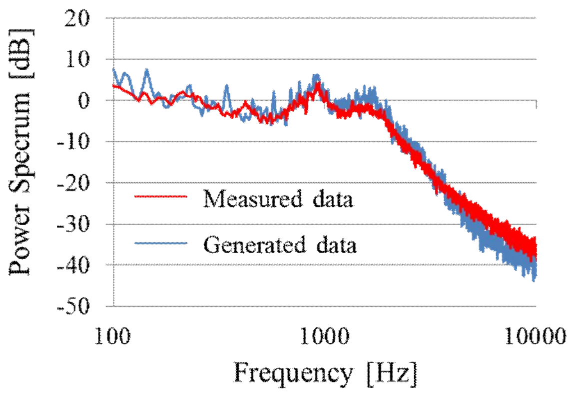


Figure 13. Comparison of power spectrum

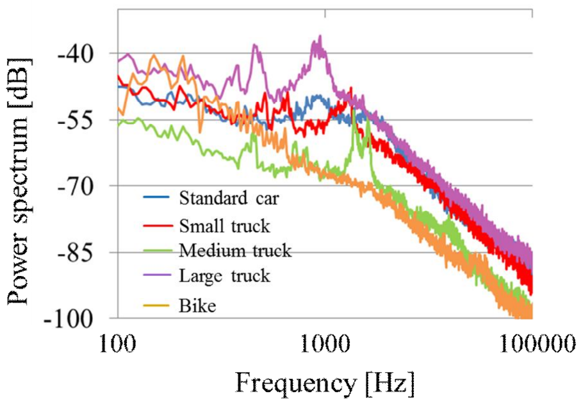


Figure 14. Comparison of power spectrum

Application example

The present system is applied the traffic simulation with various type of vehicle as shown in Fig.15. The sound source data generated from the various car driving tests is implemented to the simulation. Fig.16 shows the scene that the observer uses the system. The computed results are compared with the measured results by the noise level meter (vehicle velocity:100km/h, pavement of road:drainage pavement, passage years of pavement:0year) as shown in Fig.17. From this figure, it can be seen that the computational results are good agreement with the measurement.

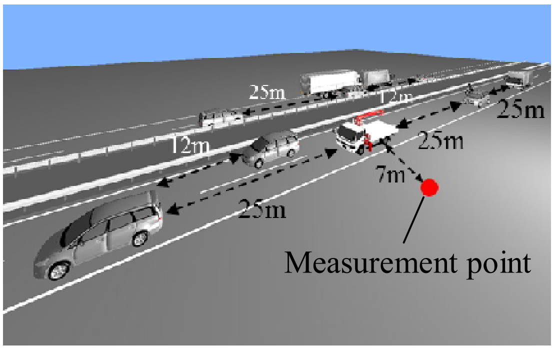


Figure 15. Computational condition

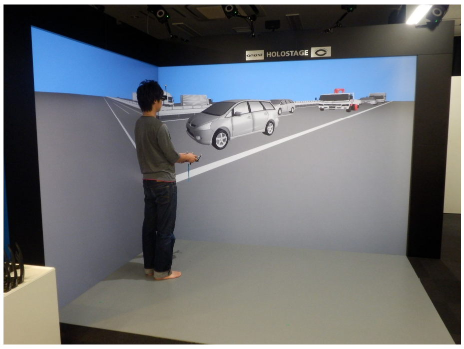
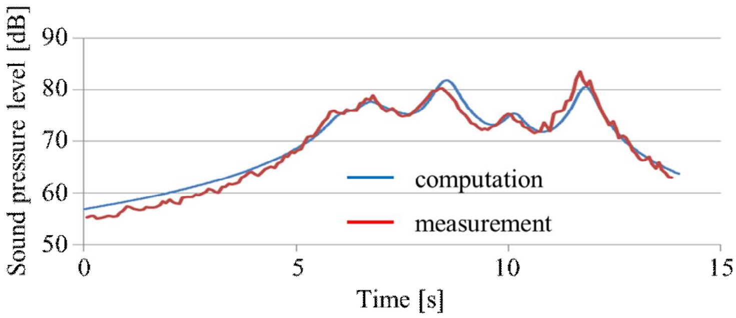


Figure 16. Scene that the observer uses the system



Figurre 17. Comparison of computational and measured results

Conclusion

A road traffic noise evaluation system based on spatialization of sound using virtual reality technology has been presented. In order to consider the effects of directivity of the sound wave and delay of the arrival time, a stereoscopic sound field has been developed in VR space. Furthermore, the sound source data for the auralization in VR space has been generated from the various vehicle driving tests. The following conclusions can be obtained.

- The reality and presence of the system has been improved by the spatialization of sound field in VR space.
- The power spectrum of generated sound source data for auralization is good agreement with the observed data, and the high quality sound source data has been obtained.

The verification of the present system to the complicated road environment is left in the future work.

References

Nagano T. Yasuda Y. Turihata K. and Yanagisawa T. (1999). "The examination of virtual reality system for noise experience", The Technical Report of The Proceeding of The IEIC, EA99-56, pp.33-40.

Makane K. and Takahashi K. (2004). "3D Traffic Noise Simulator for VR Environment ." CONVR 2004: 4th Conference of Construction Applications of Virtual Reality, Lisbon, Portugal, Sept. 14-15, 183-186.

The Acoustical Society of Japan. (2009), "Road traffic noise prediction model "ASJ RTN-Model 2008" proposed by the Acoustical Society of Japan", Journal of Japan Acoustical Society of Japan, Vol.65.

Tajika S. Kashiyama K. and Shimura M. (2009)," Development of a road traffic noise estimation system using virtual reality technology", Construction Virtual Technology 2009,pp305-314.

Shibata, K. Tajika S. Kashiyama K. and Shimura M. (2010), "Development of an experienced-based road traffic noise evaluation system using VR technology", Construction Virtual Technology, pp.513-522.

Tanigawa M. Moriya Y. Ejima K. Kashiyama K. Shimura M. (2013) , A study on three dimensional spatialization of sound with more reality for road traffic noise evaluation system based on virtual reality technology, Journal of Applied Mechanics, JSCE, Vol.16. (in Japanese) (in press)

Ward, D.B. and Abhayapala, T.D. (2001), Reproduction of aplane-wave sound field using an array of loudspeakers, Speech and Au-dio Processing, IEEE Transactions on, Vol.9, pp.697-707.