Monte Carlo simulation of long-term average noise levels and fluctuations predicted using a parabolic equation model

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Abstract

A method for predicting long-term average and level fluctuations of sound propagation was investigated by applying Monte Carlo simulation to variations in meteorological conditions. The method, which is based on a Parabolic Equation Model, assumes meteorological variation as a stochastic Gaussian process. To examine the effectiveness of our approach, we made a comparison of calculations by Monte Carlo simulation with actual noise measurements. The result shows that there are calculations clearly different from measurements in case of strong upward wind conditions for frequencies higher than 250 Hz. To improve the discrepancy between calculations and measurements in case of upward wind, we modified our approach to take effects of air turbulence into account. It was found that the additional procedure brought improvement of precision in calculation even in case of strong upward wind condition.

1. Introduction

Meteorological conditions affect outdoor sound propagation, particularly over distances greater than 100 m, even with a steady sound power level at the sound source. The sound level observed at a distant receiver can greatly vary due to the effects of temperature and wind during sound propagation. Therefore, to evaluate environmental noise in a specific area, it is important to estimate long-term average and magnitude of fluctuations of noise levels, but measurement over long periods is laborious and costly. A more effective approach is to estimate sound propagation using calculation based on statistical information on meteorological conditions. Here, we studied a Monte Carlo simulation technique as a means for estimating average and fluctuation of noise levels by assuming that meteorological conditions behave as a stochastic process. A Parabolic Equation (PE) Model [1], a kind of numerical prediction methods of sound propagation, was used as the basis of Monte Carlo simulation.

2. Monte Carlo Simulation using PE model

In our study, we evaluate average and fluctuation of sound levels at distant receivers, by taking statistics of repeated calculations of sound levels using PE Model under various meteorological conditions. We assume that meteorological conditions (temperature and wind speed) affecting sound speed change along the vertical direction. Besides, we concentrated our attention on wind speed as a variation factor affecting sound speed. That is, the vertical profile of temperature is supposed to be deterministic as one of three typical conditions (lapse, neutral and inversion), while the vertical profile of wind speed varies time to time when we make PE Model calculation. Basically, the wind profile obeys the ‘logarithm law’, but the shape changes dependent on wind speed at a reference height, and the wind speed is a random variable obeying a normal distribution with an average and a standard deviation specified based on long-term measurements. To examine the effectiveness of our approach, we made a comparison of calculations by Monte Carlo simulation with noise measurements by Parkin and Scholes [2]. Figure 1 shows two examples of comparison of excess attenuation for 125 Hz and 1 kHz 1/3octave bands. Calculations were repeated 40 times. The temperature profile was fixed to a lapse condition derived from their measurements at heights of 1.2 and 12 m, while wind profile were changed to obey the ‘logarithm law’, using a normal distribution (average: +2.1 m/s and standard deviation: 3.1 m/s), being based on their measurements of wind at a height of 10 m. Besides, the ground was assumed to be locally reacting and acoustic impedance of the ground was calculated from the flow resistivity per unit thickness $800 \times 10^3$ mks rayls/m using a modified Delany-Bazley equation revised by Miki [3]. The result of examination shows that, roughly speaking, calculations fit measurements, but there are calculations clearly different from measurements in case of strong upward wind conditions for frequencies higher than 250 Hz. In other words, shadow zones may be formed in calculations for strong upward wind conditions, but it is different from measurements.

3. PE model considering turbulence

To improve the discrepancy between calculations and measurements in case of upward wind, we modified our approach to take effects of air turbulence into account. The PE model calculates vertical sound field at each step of marching along the ground based on a vertical
sound speed profile, in which we incorporated a small stochastic component due to air turbulence. We used a simple procedure, which we derived from an algorithm proposed by Gilbert et al. [4], that is, we added a random component due to turbulence into the vertical sound speed profile after we calculated the sound speed profile based on temperature and wind speed profiles at each time of PE Model calculation. The random component was determined under the assumption that the vertical autocorrelation function of turbulence obeys a Gaussian distribution (correlation length $L = 1.1$ m and turbulence strength $\langle \mu^2 \rangle = 2.0 \times 10^{-6}$). However, although Gilbert derived a two dimensional random component distributed in height and distance, we simplified it to a random component of a single dimension in height. Figure 2 shows an example of comparison of excess attenuation for 125Hz and 1 kHz 1/3octave bands between calculations considering turbulence and measurements. The other meteorological conditions are the same as in Fig.1. The figure suggests that considering turbulence brings improvement of precision in calculation even in case of strong upward wind condition.

4. Conclusions

We proposed a method for predicting long-term averages and fluctuations of sound propagation that takes account of variations in meteorological data and

![Figure 1: Comparison of excess attenuation calculated by PEM not considering effects of turbulence with measurements by Parkin (lapse) for (upper) 125Hz and (lower) 1 kHz 1/3octave band. The mark (◊) indicates maximum and minimum of Parkin’s measurements (20 data), the mark (○) indicates mean and the mark (△) indicates ±std values.](image1)

![Figure 2: Comparison of excess attenuation calculated by PEM considering effects of turbulence with measurements by Parkin (lapse) for (upper) 125Hz and (lower) 1 kHz 1/3octave band. The marks indicate the same as Fig.1. PEM calculations were repeated 40 times by fluctuating the wind speed and indicate solid lines in Fig.1 and Fig.2.](image2)

uses the Parabolic Equation Model and a Monte Carlo simulation technique using hypothetical variations in meteorological conditions. Its suitability for practical application was evaluated by comparing the calculated results with the data measured by Parkin and Schoes. The fluctuations in the calculated excess attenuation with changes in the wind speed profiles agreed well with the measured ones. It suggests that the Monte Carlo simulation using the PE model can be successfully applicable for predicting average noise levels and fluctuations under various meteorological conditions.

5. References