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Dynamic modeling of traffic noise in both indoor and outdoor environments by using a ray tracing method

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ABSTRACT

The complexity of the urban environment and traffic characteristics give the dynamic simulation of traffic noise practical significances. A new dynamic modeling of traffic noise in both indoor and outdoor environments was proposed. First, considering multiple reflections and diffractions, 3D ray tracing method subordinated to space partitioning was used to simulate sound propagations. Then, microscopic traffic simulation which provided time-variant parameters for the vehicle emission model, was used to gain spatial and temporal outputs. Space partitioning improved the computational efficiency by transforming the global search into a local one in complex sound propagation simulation. A case was validated the accuracy, as the indoor and outdoor average errors of equivalent sound levels (L_{eq}) were respectively 1.68 dB and 1.65 dB. Moreover, less than 1.5 dB errors of statistical indicators (L_{90}, L_{50} and L_{10}) and well coincidence of statistical distributions of the instantaneous sound pressure levels ($L_{eq,1s}$) illustrated a good performance on dynamic simulation. Finally, the effects of vehicle speed, proportion of heavy vehicles and signal phase on traffic noise were discussed. The results showed that 1) Indoor/outdoor L_{eq} had logarithmic relationships with vehicle speed. 2) It presented quadratic polynomial relationships between L_{eq} and proportion of heavy vehicles. 3) Dynamic results showed that noise variations were consistent with the changes of the signal period, and it revealed different noise distributions with various vehicle statuses; upstream average L_{eq} was 3.3 dB louder than the downstream one with vehicle acceleration; average $L_{eq,1s}$ during the red light was 20 dB softer than it during the green light.

1. Introduction

The pollution of traffic noise is increasing with the growing number of vehicles. In addition, the public suffers from more pollution in both indoor and outdoor environments of buildings along the roads. Traffic noise does harm to people's normal life, work and health [1] [2]. The accurate prediction of traffic noise in both indoor and outdoor environments can provide effective information to improve people's living and working environment.

Current research on traffic noise mainly focuses on special types of road scenes [3–5], indoor building environment [6,7] and the outside surroundings of buildings [8–10]. These studies only place emphasis on the indoor or outdoor environment, and the scenes for both are rarely involved. Geometrical acoustic methods [11–13] are normally used to simulate the sound propagation in an indoor or outdoor space. Among these methods, the ray tracing method [14,15] is widely employed because it can effectively perform the reflection [16] and diffusion [17] in the propagation process with high accuracy [18]. However, when it simulates the paths that sound travels from an outdoor space to an indoor space with complex architectural layouts, a large number of sound rays are emitted, and searching the line segment intersections is a tedious work, which reduces the computational efficiency of this method. Thus, it is necessary to preprocess the indoor space to reduce the search areas of the sound rays. Space partitioning based on convex polyhedron cells is introduced to solve this problem in this paper.

The traditional noise simulation method is used only for static sound sources. The real-time changing characteristics of traffic noise are hard to predict by using the ray tracing method. As the

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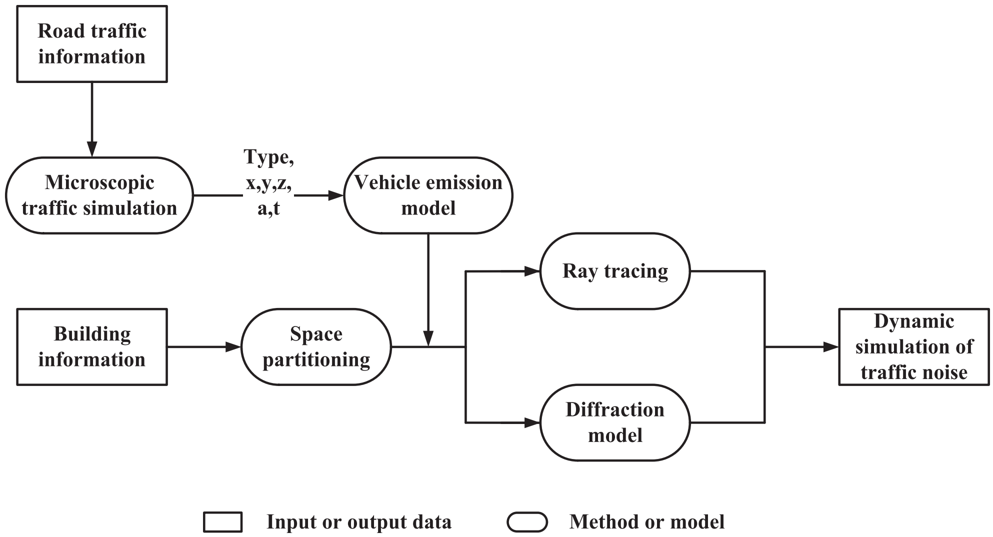

Fig. 1. Overview of the dynamic model on traffic noise in both indoor and outdoor environments.

technology of computational sciences evolves, dynamic noise simulation technology [19,20] that combines traffic flow simulations with noise calculations is extensively applied to solving this issue. The technology can accurately simulate the running state of traffic flow and its influence on noise in complex urban road environments [21,22]. In addition, the change of dynamic real-time noise can be reflected. The outdoor noise simulation [23–25] and the effects of different traffic factors on the noise in indoor and outdoor environments [26,27] are mainly assessed with this technology. Wei-li Luo discussed the effects of the speed limit and traffic signal intersections on traffic noise in the Guangzhou Women & Children Medical Care Center [28]. Arnaud Can analyzed the signal control measures on the noise reduction at intersections [29]. These studies only examined the exteriors of buildings without considering the dynamic noise characteristic from the exteriors to the interiors of buildings.

Nonlinear models, such as fuzzy mathematics calculation model [30], neural network model [31], are extensively used, as they can effectively solve complex noise prediction problems. These models are verified in noise simulation [32] and other fields [33,34]. In the process of dynamic modeling of traffic noise and data manipulation, these models are referred.

The previous studies mainly focused on the indoor or outdoor noise calculation by using noise simulation without considering the real-time changing characteristics or dynamic noise simulation technology. Both indoor and outdoor spaces are less contained, and the effects of traffic factors on noise in the indoor environment are too little involved. In this paper, considering the reflection and diffraction, a dynamic model of traffic noise in both indoor and outdoor environments is realized based on the ray tracing method. An appropriate vehicle emission model is also incorporated into the dynamic modeling by using microscopic traffic simulation. Space partitioning is introduced to improve the computational efficiency of the ray tracing method by simplifying the process of searching for the line segment intersections. Building A, in Guangzhou, China, is chosen to verify the exactness of the method. Vehicle speed, the proportion of heavy vehicles and signal phase are assessed in order to analyze the effects of traffic factors. The paper achieves two new objectives. First, the 3D dynamic modeling of traffic noise based on space partitioning, using the ray algorithm from the exteriors to the interiors of buildings, is created as an original work. Second, using the dynamic modeling, the study of the effects of partial traffic factors on the dynamic noise distribution in both indoor and outdoor environments, is the application of the dynamic simulation.

2. Methods

2.1. Overview of the model

The model is based on the basic assumption that the sound waves are non-flexural, which propagate in line in both indoor and outdoor environments. Fig. 1 shows the overview of the dynamic model on traffic noise in both indoor and outdoor environments. The part of using 3D ray tracing method incorporated in the dynamic traffic simulation software is an indispensable and original work. First, the indoor space is divided into several units according to the architectural layout. Sound rays are tracked in the structure generated by the subdivision. The search area of the intersection judgments of sound rays becomes the separate local parts instead of a global part. Therefore, the goal of the simplified calculation is achieved. Second, with the help of microscopic traffic simulation, which provides time-variant parameters including types, coordinate positions (x, y, z), acceleration (a) and time (t) of vehicles, noise emission can be obtained. Third, considering the reflection and diffraction, the instantaneous sound pressure levels (the time evolution of the equivalent sound level of 1 s, $L_{eq,1s}$, in dB) are determined by using the ray tracing method in the divided space. Finally, the results of the equivalent sound levels (the A frequency weighting, L_{eq}, in dB) in both indoor and outdoor environments are presented.

2.2. 3D ray tracing method based on space partitioning

The ray tracing method can simulate a variety of propagation phenomena. Each vehicle is seen as an omnidirectional point source. Every wall of the acoustic space is assumed to be flat in this method. Point source sends out sound rays in every direction. The phenomena of the reflection and diffusion occur in the sound propagation process. By recording time and energy data carried by the sound rays, the whole 3D sound distribution can be acquired.

In the traditional ray tracing method, because complicated methods [35,36] are used to search for the only collision point of