The 3D simulation of indoor traffic noise in multi-storey buildings based on Beam Tracing Method

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ABSTRACT

Traffic noise has become an issue of concern for urban residents. Moreover, multi-storey buildings are common in urban area. However, there are few studies focusing on indoor traffic noise distribution of multi-storey buildings. In order to simulate the indoor sound field of multi-storey buildings, this paper presents a revised beam tracing method which was based on triangular-prism space subdivision. The triangular-prism subspaces were classified according to the storey they belong to, so that a sound beam only spread in the storey it has entered. Firstly, the proposed model subdivided the whole area into triangular-prism subspaces according to the building layout and storey-heights. Meanwhile, the model differentiated indoor and outdoor subspaces. Then, traffic noise propagation was simulated by using beam tracing method, and a stab-tree data structure was constructed to record the noise propagation. Finally, the propagation paths from each source point to each receiver point were found by traversing the stab-tree data structure, and sound energy of each path was calculated to get noise level of each receiver point. Examples were given at the end of the article and prove the method to be effective.

Keywords: Traffic noise, Beam tracing, Multi-storey
I-INCE Classification of Subjects Number(s): 52.3

1. INTRODUCTION

Nowadays, traffic noise pollution is having a growingly negative impact on our daily life. With the improvement of living standard, people tend to pay more attentions on sound level of their living environment, especially the indoor sound distribution relative to outdoor noise.

There were some researches relevant to the noise of multi-storey buildings. Some researches analyzed the impact of traffic noise on the high-rise building and focused on outdoor sound distribution (1–3). Some researches studied the relationship between floor numbers of multi-storey buildings and the sound condition in balconies (4–8). There also were few studies focus on indoor noise of multi-storey building, such as work shown in the reference (9).

Few studies have concentrated on indoor sound field distribution, which was caused by outdoor traffic noise. Nevertheless, indoor sound field simulation of multi-storey building could provide advices on the selection of building layouts and location. It could be helpful to put forward better noise control measures and provide references for the design of buildings.

In order to simulate indoor noise distribution caused by traffic noise, this paper presented a three-dimensional noise simulation model for the interior and exterior of multi-storey buildings based on Beam Tracing Method (10). The proposed model subdivided the calculation area into triangular-prism subspaces according to building layout and storey-heights. Because lots of buildings could be seen as columns in abstract, this kind of spatial subdivision method would be universal and could accelerate the beam tracing process.

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2. METHODOLOGY

The process of the proposed model could be divided into 4 phases, spatial subdivision, beam tracing, path generation and noise calculation.

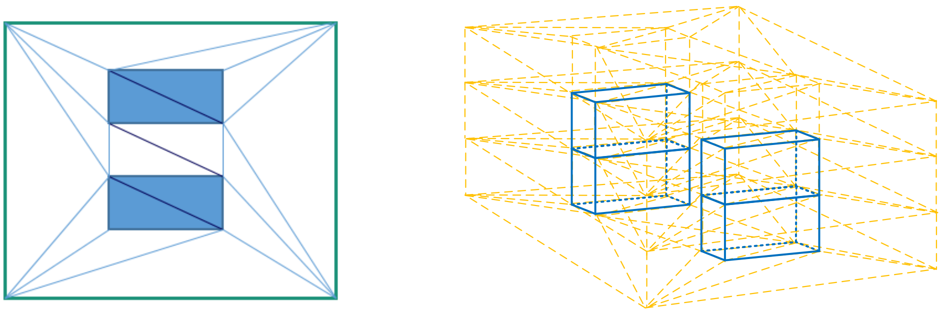
2.1 Spatial Subdivision

The function of spatial subdivision was to accelerate beam tracing. In spatial subdivision phase, the process could be divided in 2 parts, two-dimensional triangulation in the horizontal plane and three-dimensional spatial subdivision of the area.

In the first part of this phase, subdivided the horizontal plane into triangles according to the vertexes of buildings and the boundary of the calculation area. Firstly, projected the buildings and area boundary to get vertexes of buildings and boundary. Secondly, a triangle-network was created based on Constrained Delaunay Triangulation (11), constrained by building layouts and area boundary. In the triangulation process, each triangle was numbered and the adjacent relation of triangles was established. Each edge of the triangle-network had an attribute that records the property of the edge, namely, edges representing external walls of the building, indoor walls of the building, outdoor imaginary edges and indoor imaginary edges.

In the second part of spatial subdivision phase, subdivided the whole area into triangular-prism subspaces. The process was based on the triangle-network created in the last step. Stretched the two-dimensional triangle-network along with vertical direction to form triangular-prisms. Then subdivided the triangular-prisms again according to the heights of storeys, so that triangular-prism subspaces were formed, and each one of them was given an index. After that, the attribute of each subspace boundary surface was identified automatically. Additionally, each subspace was identified whether it was indoor or outdoor, and the storey each subspace belonged to was identified. The adjacent relation of subspaces was also established.

Figure 1– An example of spatial subdivision was an example of spatial subdivision. Figure 1(a) was a triangle-network created based on Constrained Delaunay Triangulation, the blue rectangles represented projection of buildings on the horizontal plane. Figure 1(b) was the spatial subdivision result.



(a) (b)

Figure 1 – An example of spatial subdivision

2.2 Beam Tracing

In beam tracing phase, used Beam Tracing Method (10) to construct Stab-Tree structure (12) to record noise propagation sequences.

Each Stab-Tree recorded the propagation of one sound source point, so sound source points were traced separately. Each trace process was started from the source point. When a sound beam met a subspace boundary surface, it would form its sub-beams according to the attribute of surface, and sub-beams would continue to propagate in the neighboring subspace of that surface. Meanwhile, a child node would be added to the Stab-Tree when a sub-beam was formed. Each child node recorded the subspace index which it located in, the location of source point, the entering range of the sound beam, reflection time, diffraction time, the location of each reflection, the location of each diffraction and so on. The circulation continued until reaching the preset propagation thresholds.

There were some differences between outdoor and indoor sound propagation. In spatial subdivision phase, the model had differentiated indoor and outdoor subspaces, and triangular-prism subspaces had been classified according to the storey they belong to. On this basis, when a sound beam entered a subspace which was indoor subspace, the model could restrict the sound beam to spread only in the storey it had entered, until it reached the propagation thresholds or the sound beam returned to outdoor subspace.

Figure 2 shows an example of outdoor beam tracing in two-dimensional horizontal view and the corresponding Stab-Tree. Point S means a sound source point, point R means a receiver, and the rectangles in heavy line present the projection of buildings in the horizontal plane.

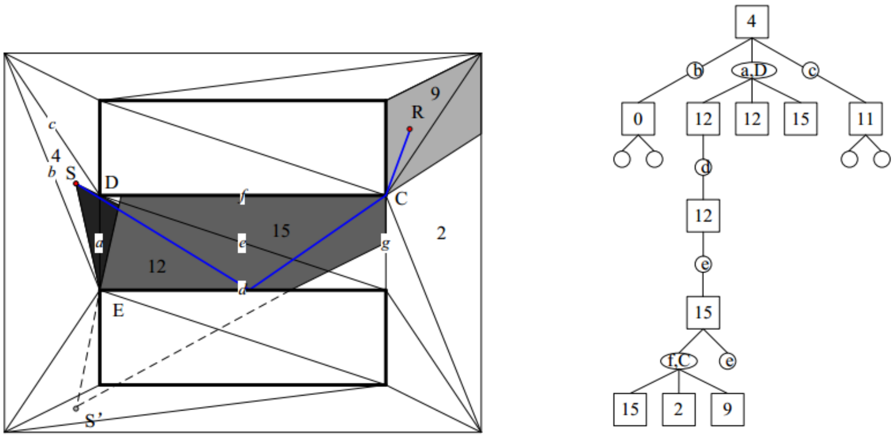


Figure 2 - An example of beam tracing

2.3 Path Generation

For each pair of receiver and sound source, the sound propagation path could be generated quickly through the corresponding Stab-Tree structure.

For every receiver, found out which subspace the receiver was located in. Then traversed all nodes of the Stab-Tree structure, and judged whether the receiver was in the range of the beams of node. If the receiver was in the range of the beams, the path recorded by that node was an effective path from the source to the receiver. Therefore, that effective path, which was one of the propagation paths from that source point to that receiver point, could be generated by a back trace from the child node to the father node.

2.4 Noise Calculation

After getting effective paths by the stab-tree structure, use noise attenuation formulas to get noise contribution of each path.

First step was getting noise sources. Some studies (13,14) have shown that the road traffic noise sources can be regarded as a line source when the vehicle flow is enough large. And the line source could be discretized into a set of point sources, as shown in Figure 3.

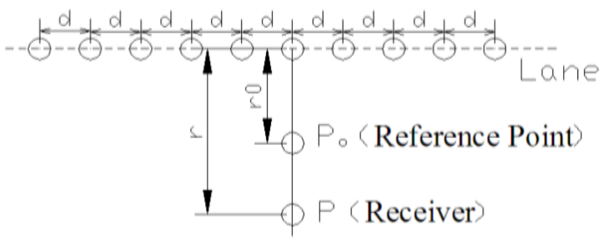


Figure 3 - Line sound source discretization

Each of the point sources represents a single vehicle. According to the Chinese specification (15), the relationship between average noise value of reference point which is 7.5m away from the lane and velocity is:

$$L_0 = \Delta C_\alpha + \begin{cases} 27.96 + 24.92\lg(v), \text{small car} \\ 16.44 + 36.73\lg(v), \text{midlle car} \\ 31.77 + 29.71\lg(v), \text{large car} \end{cases} \tag{1}$$

In this formula, v means the velocity of the car, and ΔC_{α} means an accelerate coefficient which equals to 0 when the car moves at a constant speed.

After getting noise contribution of each path, superposed noise values of all effective paths to get the sound level of all receivers.

3. EXAMPLE

Adapted the proposed model to a simple example of a multi-storey building. The layout of the building is shown in Figure 4 and Figure 5. Figure 4 is the vertical view of the building layout. Figure 5 is the longitudinal section of the red line in Figure 4. The point S means a sound source point, blue lines present windows and yellow lines present walls.

The size of the building was 12m×16m. The height of each storey was 4 meters. The length of the widest window was 8 meters and the lengths of the other two windows were both 4 meters. The widths of windows were all 1.8 meters. The sound source point was on the left side of the building and was on the red line in Figure 4. The distance between source point and the building was 4 meters. The source point was a small car at a steady speed of 60km/h. The preset reflection threshold was 3 times and diffraction threshold was once. The background noise of the area was 40dB.

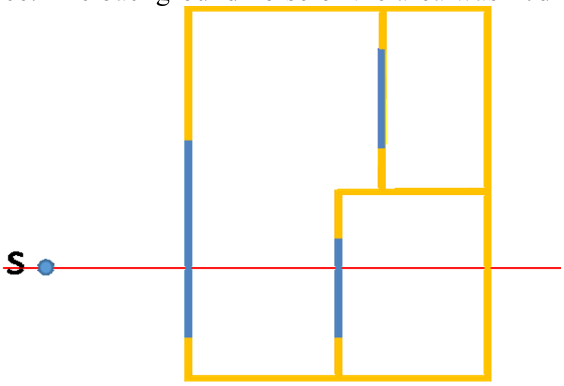


Figure 4 – Buidling layout of the example (in vertical view)

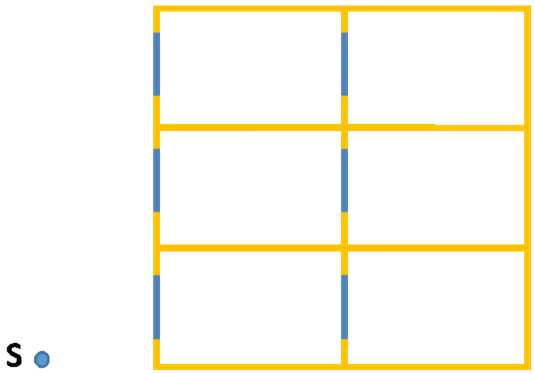


Figure 5 - Buidling layout of the example (longitudinal section)

The noise simulation result in the vertical plane of Figure 5 is shown in Figure 6.

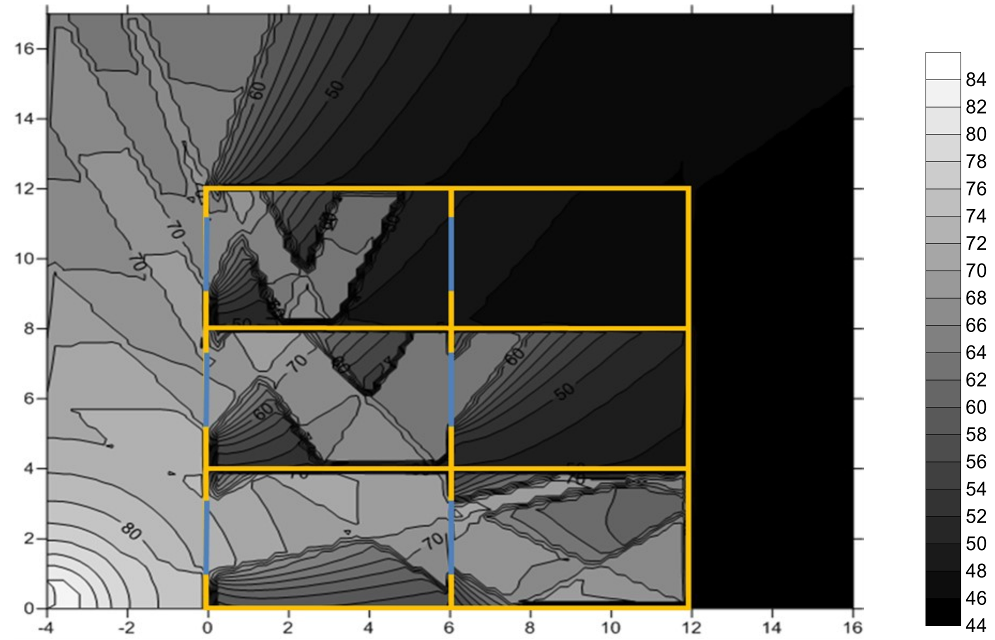


Figure 6 - The noise simulation result

In order to get a better observation of the result, this example used a source point as the sound source. And road traffic noise simulation result could be obtained by superposing many simulation results of source points. From the simulation result above, we can see that the sound was reflected when it met the walls, ceiling and floor of the building, and it diffracted when it met an edge of a window or the roof of the building. And the propagation basically matched the reality.

4. CONCLUSIONS

This study proposed a kind of beam tracing method based on triangle-prism subdivision, and the spatial subdivision was in accordance with building layout and storey-heights. The model was suitable to indoor and outdoor noise propagation simulation for multi-storey buildings. An example was given to prove the effectiveness of the model.

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REFERENCES

1. Pamanikabud P, Tansatcha M. 3D analysis and investigation of traffic noise impact from a new motorway on building and surrounding area. Applied Acoustics. 2010;71(12):1185–93.
2. Pamanikabud P, Tansatcha M. Geoinformatic prediction of motorway noise on buildings in 3D GIS. Transportation Research Part D: Transport and Environment. 2009;14(5):367–72.
3. Lee PJ, Kim YH, Jeon JY, Song KD. Effects of apartment building fa??ade and balcony design on the reduction of exterior noise. Building and Environment. 2007;42(10):3517–28.
4. Li KM, Lui WK, Lau KK, Chan KS. A simple formula for evaluating the acoustic effect of balconies in protecting dwellings against road traffic noise. Applied Acoustics. 2003;64(7):633–53.
5. Ishizuka T, Fujiwara K. Full-scale tests of reflective noise-reducing devices for balconies on high-rise buildings. The Journal of the Acoustical Society of America [Internet]. 2013;134(2):EL185–90. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23927223
6. May DN. Freeway noise and high-rise balconies. Journal of the Acoustical Society of America [Internet]. 1979;65(3):699–704. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-0018445948&partnerID=40
7. Naish DA, Tan ACC, Demirbilek FN. Simulating the effect of acoustic treatment types for residential balconies with road traffic noise. Applied Acoustics. 2014;79:131–40.
8. Hossam El Dien H, Woloszyn P. Prediction of the sound field into high-rise building facades due to its balcony ceiling form. Applied Acoustics. 2004;65(4):431–40.

9. Mak C, Leung W, Jiang G. Measurement and prediction of road traffic noise at different building floor levels in Hong Kong. Building Services Engineering Research and Technology. 2010;31:131–9.
10. Heckbert PS, Hanrahan P. Beam Tracing Polygonal Objects. SIGGRAPH Comput Graph. 1984;18(3):119–27.
11. Berg M de, Cheong O, Kreveld M van, Overmars M. Computational Geometry: Algorithms and Applications. 3rd ed. Berlin: Springer; 2008. 191-218 p.
12. Teller SJ. Visibility computations in densely occluded polyhedral environments. University of California at Berkeley; 1992.
13. De Coensel B, De Muer T, Yperman I, Botteldooren D. The influence of traffic flow dynamics on urban soundscapes. Applied Acoustics. 2005;66(2):175–94.
14. Bhaskar A, Chung E, Kuwahara M. Development and implementation of the areawide Dynamic ROad traffic NoisE (DRONE) simulator. Transportation Research Part D: Transport and Environment. 2007;12(5):371–8.
15. Specifications for Environmental Impact Assessment of Highways. JTG B03-2006 China: Ministry of Transport of the People's Republic of China; 2006.