Title:
Virtual Reality for Case-based Learning of The Propagation of Urban Traffic Noise in Residential Areas

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Introduction:
Environmental impact assessment was introduced in universities in the 1970s and nowadays it has been well established in higher education worldwide [1]. Legislation in more than 180 countries or regions stipulates that environmental impact assessment must be conducted before construction projects start and therefore there is a growing demand for certified experts such as registered environmental impact assessment engineers in China. In engineering education and vocational training of environmental impact assessment, noise propagation and attenuation are indispensable teaching contents. With the construction of urban traffic networks, noise pollution caused by road traffic and rail transit has been in focus for the last few years [2]. Consequently, practitioners need to learn the propagation of urban traffic noise in residential areas.

Case-based learning utilizes historical or hypothetical cases that involve solving problems and/or making decisions and it has been successfully adopted in the teaching of law, business, medicine, science and engineering courses [3]. Well-designed teaching cases inspire trainees to do more thinking and aid them in understanding abstract theoretical knowledge, which is especially suitable for vocational training. In terms of engineering education and vocational training for the propagation of urban traffic noise in residential areas, case-based learning can reflect the characteristics and interactions of environmental elements such as terrain, traffic, buildings, residents and plants, assisting trainees to grasp the theoretical knowledge and professional skills of environmental impact assessment more systematically and to apply them to engineering projects more efficiently. Different from general teaching cases with descriptive texts and on-site photos as the description of case scenarios, teaching cases for the propagation of urban traffic noise in residential areas need to present noise intensity and noise distribution of case sites. Interactive audio-visual experience is more intuitive and thus preferable.

Virtual reality brings participants a sense of presence by deceiving people's senses and provides them with humanized man-machine operations and natural feedback in a virtual environment, which is helpful for higher education and vocational training [4]. The combination of case-based learning and virtual reality provides vivid audio-visual presentations and rich interactive content and significantly improves teaching quality [5]. As far as case-based learning of the propagation of urban traffic noise in residential areas is concerned, virtual reality-based teaching cases can reflect the visual and auditory characteristics of environmental elements through 3D models and audio playback, restoring terrain,

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traffic, buildings, facilities, residents and plants in real environments with high fidelity. However, noise at different positions in the virtual environment of a teaching case should be different. Ignoring the propagation and attenuation of noise is acceptable for small-scale scenes, but not convincing for larger or more complex scenes such as urban residential areas. Consequently, it is time-consuming to establish teaching cases for the propagation of urban traffic noise in residential areas, and it is challenging to provide intuitive and interactive audio-visual experiences in the virtual environment of these teaching cases.

In this study, we present a virtual reality-based case generation system for the propagation of urban traffic noise in residential areas. Virtual scenes of urban residential areas with surrounding traffic and noise reduction facilities are built based on virtual reality. The noise in the scenes is computed using noise mapping and then fed back into the scenes to establish complete audio-visual teaching cases. The virtual environment of the teaching cases makes the association between the virtual scene and the noise environment and ensures the synchronization between scene roaming and noise experience. Additionally, a case study is conducted for an urban residential area in Beijing with its surrounding traffic to verify the validity and vividness of the proposed case generation system.

Methodology:

The proposed case generation system is established based on Unity, a virtual reality development toolkit. It consists of three modules, namely scene modelling, noise prediction and system management. The scene modelling module constructs the 3D virtual scene of urban residential areas with surrounding road traffic, rail transit and noise reduction facilities. The noise prediction module performs the conversion of the virtual reality scene into a geographic information model, the calculation of the noise environment in the virtual scene and the generation of virtual reality-based teaching cases. The system management module configures the operation authority of project staff to protect key data hierarchically and records operation logs for problem tracing. Figure 1 shows the workflow of the proposed case generation system.

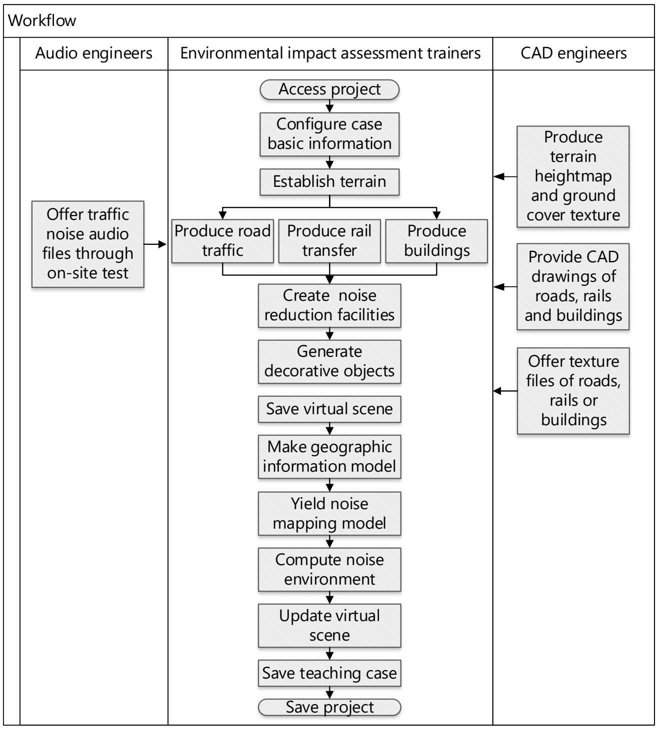

Fig. 1: The workflow of the proposed case generation system.

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Scene modelling underlies the forecast and evaluation of the noise environment in urban residential areas and thus it requires geometrically accuracy and perceptually fidelity. There are growing impressive works that designed and implemented virtual reality-based 3D environments in recent years [6,7]. Therefore, virtual reality is adopted for scene modelling of urban residential areas with surrounding traffic and noise reduction facilities. There are five main types of scene objects in the virtual scene, namely terrain, building, road traffic, rail transit and noise reduction facility. The terrain is the basis of a 3D scene and it enhances the realism of the scene. The terrain object in a scene is produced by reading a heightmap file, a grayscale image in which different grayscales represent different heights. Buildings are the main body of a 3D scene, reflecting the stereoscopy and uniqueness of the scene. Road traffic and rail transit are noise sources in the area and they increase the complexity of the virtual scene. The geometry and layout of buildings, roads and rails in the residential area are programmatically obtained from the corresponding layers of CAD drawings. Noise reduction facilities serve to reduce noise and display information or art and they are the embodiment of traffic noise control in the scene. They can be built parallel to roads and rails in the case generation system. Texture files are configurable for road surfaces, building façades, building roofs and noise reduction facility surfaces. Besides, there are some decorative objects in the scene, such as people, plants and street lights. They are generated randomly or uniformly in specific areas of the scene based on a built-in 3D model library.

Level prediction and impact assessment of noise pollution are usually performed based on noise mapping [8]. For traffic noise, noise mapping computes the noise distribution in an area according to the noise source and propagation models such as FHWA, CNOSSOS-EU and ASJ RTN. In China, the noise prediction model in technical guidelines for noise impact assessment HJ 2.4-2009 plays a pivotal role in the forecast and evaluation of traffic noise pollution [9]. The proposed case generation system adopts the noise prediction model HJ 2.4-2009 to compute the noise in the virtual scene corresponding to the residential area affected by urban traffic noise. The type, speed and acceleration of each vehicle are assigned to the noise emission model for the noise production computation. The position and noise emission of each vehicle is allocated to the sound propagation model for the individual contribution calculation at a particular time. The calculated noise is then fed back to the virtual scene. The audio signal of an attenuated noise is attained by filtering that of the original noise with a graphic equalizer based on the octave frequency band A-weighted sound pressure level of the sound attenuation from the reference point to the prediction point. The audio signal of each attenuated vehicle noise is superposed to obtain the noise signal at a particular moment and a specific location in the scene. The virtual scene is consequently associated with the noise environment, which established a complete audio-visual teaching case based on the residential area. For recording the user's subjective experience during scene roaming in real-time, a pop-up list containing five levels is designed for users to select their noise annoyance levels. The subjective perception of noise is stored together with location information, which permits a comparison between objective calculation and subjective perception.

Results:

Take a residential area in Beijing as a case of the propagation of urban traffic noise in residential areas, as shown in Figure 2. There are 26 buildings in the residential area, most of which are for residential use and a few for commercial use. The buildings in the residential area are mainly arranged in four columns, the height of which gradually decreases from west to east. The buildings in the westernmost column have eight floors, with a gable roof on top. The buildings in the easternmost column have three floors, with a pyramid roof on top. The residential area has five entrances, one in the north, one in the east and three in the south. Cars can enter and leave the residential area through the north or south entrance. The southwest entrance of the residential area is connected to the entrance of an underground parking lot.

There are four roads around the urban residential area. The road on the west side of the residential area is an urban arterial road with heavy traffic. The other three roads are branch roads and the traffic flow on the north side of the residential area is significantly larger than that on the south and east side of the residential area. No additional noise reduction facilities, such as sound barriers, are installed along these roads. Rail transit lines in this region are underground and far away

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from the residential area, which means that rail transit has little impact on the noise environment of the area. Therefore, the contribution of rail transit is ignored during the noise pollution assessment of the residential area.

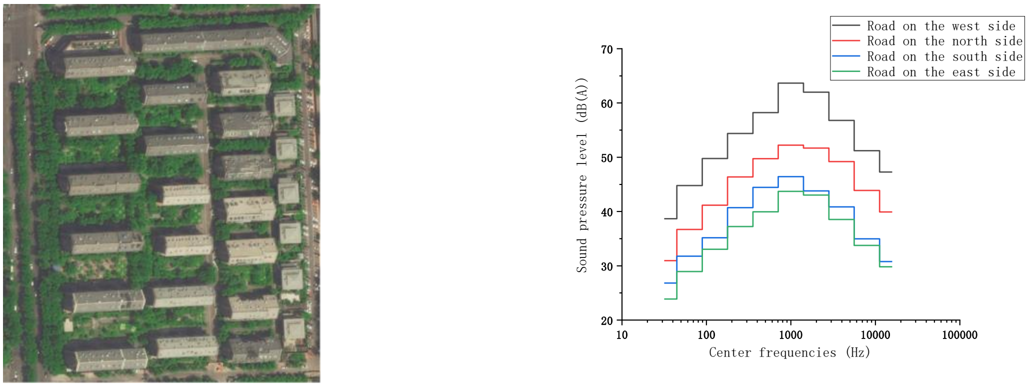

Fig. 2: A residential area in Beijing as a case: (a) Residential area, (b) Octave frequency band A-weighted sound pressure level of road traffic near the residential area.

To confirm the validity of the proposed case generation system for the propagation of urban traffic noise in residential areas, a teaching case was established based on the above residential area. The virtual scenes of the teaching case are Illustrated in Figure 3. Different from conventional teaching cases describing case sites based on descriptive texts and on-site photos, the teaching case produced by the proposed case generation system provides virtual reality-based audio-visual case scenarios. It allows trainees to hear intuitively and interactively the noise in real-time while roaming in 3D virtual scenes. When a trainee is at the north entrance of the residential area in the virtual scene, the synthetic audio played here is about 60 dB and is a bit noisy. When he reaches the intersection near the children's play area inside the residential area in the virtual scene, the synthetic traffic-induced environmental noise here is less than 55 dB and is relatively quiet. Environmental impact assessment trainers may design roaming routes and configure predetermined evaluation locations in the virtual reality-based teaching case of an urban residential area. Trainees can experience the effect of road location and building layout on traffic noise propagation and attenuation along these roaming routes and perceive their annoyance changes and attention shifts caused by environmental noise with different intensities at different predetermined evaluation locations.

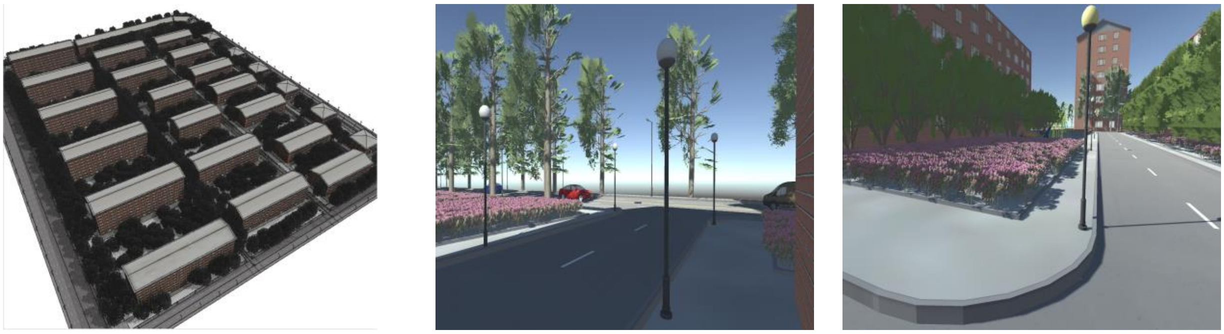

Fig. 3: Virtual scenes in the teaching case: (a) Virtual scene, (b) The north entrance of the residential area, (c) The intersection near a children's play area inside the residential area.

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Conclusions:

There has been an increased recognition that more attention needs to be paid to engineering education and vocational training for environmental impact assessment of noise pollution. With the rapid development of urban traffic networks, traffic noise pollution plays an important role in urban environment pollution and thus the propagation and attenuation of traffic noise in residential areas need to be learned by practitioners. Providing a vivid virtual environment for active learning based on historical or hypothetical cases, the combination of case-based learning and virtual reality stimulates trainees' interest in learning and significantly improves teaching quality. Nevertheless, the case generation for traffic noise propagation in urban residential areas is time-consuming, and the audio-visual association in the virtual environment of these teaching cases is challenging. The objective of this work is to propose a case generation system that produces intuitive and interactive teaching cases for the propagation of urban traffic noise in residential areas. The 3D scene is established for an urban residential area with surrounding traffic and noise reduction facilities based on virtual reality. Noise in the virtual scene is computed using noise mapping and then fed back into the scenes to associate the virtual scene with the noise environment and to synchronize scene roaming with noise experience, which forms a complete audio-visual teaching case. A case study is provided based on an urban residential area in Beijing with its surrounding traffic, verifying the vividness of the virtual reality-based teaching case and the validity of the proposed case generation system.

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