Sound propagation at micro-scale in urban areas

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ABSTRACT

Whilst large scale noise-mapping techniques have been applied extensively in practice, as required by the EU Directive on environmental noise, they are often not applicable for micro-scale urban areas such as a street or a square. This talk will discuss a series of simulation techniques as well as related acoustic theories for accurately calculating the sound field for micro-scale urban areas. This includes energy-based image source methods for street canyons and urban squares with geometrically (specularly) reflecting boundaries, image source method considering interference, ray-tracing, radiosity model for diffusely reflecting boundaries, transport theory, equivalent source method, and some other models. Techniques for urban acoustic animation will also be briefly discussed.

1. INTRODUCTION

As most acoustic problems cannot be resolved purely through practical analysis, engineers heavily rely on computer simulation which is continuously developing. Essentially, models for calculating sound distribution in urban areas can be classified into two groups: micro-scale and macro-scale. The former are often based on simulation techniques and used for accurately calculating the sound field for small and medium scale urban areas, such as a street or a square. The latter normally involve statistical methods and simplified algorithms, and are generally adopted for analysing sound distribution in large areas. In this paper, modelling techniques for sound propagation at micro-scale in urban areas are reviewed [1].

2. IMAGE SOURCE METHOD

The image source method treats a flat surface as a mirror and creates an image source. In other words, the boundaries are regarded as geometrically reflective. The reflected sound is then modelled with a sound path, directly from the image source, to a receiver. Multiple reflections are achieved by considering further images of the image source. For each reflection, the strength of the image source is reduced due to surface absorption [2,3]. A disadvantage of the image source method is that the calculation speed is reduced exponentially with increasing orders of reflection as the number of images increases. In addition, validity and visibility tests are required for image sources. Figure 1 illustrates the distribution of image sources in an idealised urban street.

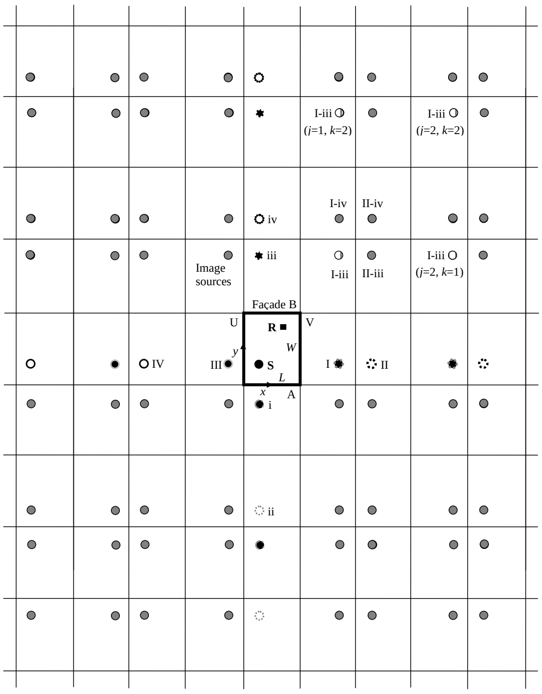

Figure 1. Distribution of image sources in an idealised square, plan view.

3. RAY-TRACING METHOD

Ray-tracing method is another commonly used simulation method. It creates a dense spread of rays, which are subsequently reflected around a space and tested for intersection with a detector (receiver) such as a sphere or a cube. A sound ray can be regarded as a small portion of a spherical wave with vanishing aperture, which originates from a certain point. Particle-tracing method uses similar algorithms to ray-tracing, but the method of detection is different. With the particle model, the longer a particle stays in the detector, the higher its contribution to the energy density is. Beams are rays with a non-vanishing cross-section. The beams may be cones with a circular cross-section or pyramids with a polygonal cross-section. By using beams, a point detector can be used, instead of a sphere or a cube. Beams are reflected around a space and tested for illumination of the detector. An advantage of ray-, particle-, and beam-tracing methods, is that they can be used for relatively complicated urban configurations, but they are usually used for acoustically smooth boundaries, namely geometrically reflective boundaries. Since there are always some irregularities on building or ground surfaces, it is necessary to consider diffuse reflections from boundaries, namely diffusely reflecting boundaries.

4. RADIOSITY METHOD

The radiosity method provides an effective way for considering diffusely reflecting boundaries. The method functions by dividing boundaries, in a space such as an urban street or square, into a number of patches (i.e. elements) and replaces the patches and receivers with nodes in a network. The sound propagation within the space can then be simulated by energy exchange between those nodes. Various computer programs have been developed based on radiosity method, which are applicable to urban spaces such as street canyons and urban squares [4, 5, 6]. A model combing ray-tracing and radiosity has also been developed and well validated against measurements [5].

5. TRANSPORT THEORY

Sound propagation may be simulated by a ray beam that represents the path of a sound particle or phonon. The phonon obeys classic mechanics laws according to the Hamilton stationary action principle. Based on the concept of sound particles and the application of the classic theory of particle transport, a model has been developed to predict the temporal and spatial sound distribution in urban areas [7, 8]. In the model a particle undergoes a straight line until it meets an obstacle, and interactions and collisions between particles are neglected. It is assumed that the effects of phase cancellation and addition are averaged and the sound sources are not correlated. The model can consider partially diffusely reflecting building façades, scattering by urban objects, atmospheric attenuation and wind effects.

6. FINITE ELEMENT METHOD AND BOUNDARY ELEMENT METHOD

Acoustic FEM and BEM are based on the approximation to the wave equation. The methods can model resonances in the frequency domain and wave reflections in the time domain. They have been successfully applied in acoustic simulation of small spaces where the wavelength is larger or at least of the same order as the room dimensions. The application range has also been extended to relatively large spaces including urban streets.

A two dimensional boundary element numerical model was used to study the sound field in the region of balconies in a tall building close to a roadway [9]. This is a typical situation where energy-based models are less appropriate since the wavelengths are not small compared to the dimensions of the balcony spaces and building elements. It was found that treatment of the ceiling or the rear wall of the balcony is the most efficient in terms of noise reduction.

7. EQUIVALENT SOURCES METHOD FOR PARALLEL STREET CANYONS

The basic idea of the equivalent sources method is to reduce a problem to a simplified geometry with boundary conditions which are easy to handle. On boundaries with different conditions, virtual sources are placed, with their strengths adjusted by solving an equation system so that the boundary conditions are fulfilled everywhere. The method has been developed for sound propagation in two parallel street canyons by Ögren and Forssen [10], where a two-dimensional configuration was considered. For the source canyon, the geometry is divided into two parts, the domain inside the canyon and the half space above. The problem can be handled by considering radiation into a half space by a Rayleigh integral and a sound field in a rigid cavity by a modal approach. In the street canyon the actual source can be considered by taking into account the vehicle flow density, percentage of heavy vehicles and velocity. The coupling between the half space and the cavity is obtained by a set of equivalent sources at the opening of the street canyon which correct the field impedance along the boundary. The opening (boundary) is divided into equally sized elements of one-tenth of the wavelength, and the corresponding equivalent sources are approximated with a piecewise constant complex source strength. The loss factors from the street boundaries and from air absorption are also considered.

8. FINITE-DIFFERENCE TIME-DOMAIN METHOD AND PARABOLIC EQUATION METHOD

The FDTD model is based on numerical integration of the linearised Euler equations in the time domain [11]. It solves the moving-medium sound propagation equations, taking into account the combined effect of multiple reflections, multiple diffractions, inhomogeneous absorbing and partly diffusely reflecting surfaces. An advantage of FDTD compared with ESM and BEM is its applicability for a moving, inhomogeneous and turbulent atmosphere, namely the consideration of the effects of refraction. Hence the FDTD can be considered as a complete model.

The PE model is based on a one way wave equation in the frequency domain. It is suitable for long range sound propagation over flat ground, but less suitable in situations with several reflecting obstacles and arbitrary wind fields [12, 13].

Since the computational resources needed for FDTD simulations are large, Van Renterghem et al used a coupled FDTD-PE model [14], where the FDTD is applied in the complex source region and the PE is used for propagation over flat ground to a distant receiver. The coupling of the two models occurs at a vertical array of intermediate receivers located at the boundary of the source region. The FDTD results are used to generate starting functions for PE.

9. EMPERICAL FORMALAE

For urban designers, it would be useful at the design stage to use relatively simple formulae to estimate the sound propagation in micro-scale urban areas. Based on both analytic theory and regression of data obtained using computer simulation models, a series of formulae have been developed for calculating the reverberation time (RT), early delay time (EDT) and sound pressure level (SPL), under various boundary conditions [1].

10. OTHER MODELS

Whilst many models concentrate on the sound propagation, attentions have also been given to the effects of traffic sources. A series of models developed [15, 16] consider different representations of equivalent point sources for various classes of vehicles, and the time-average sound level within an urban system, especially street canyons. The change of average vehicles speeds and vehicle speed limits are also taken into account.

Combinations of various models have also been proposed. For example, Ismail and Oldham suggested that a possible approach to the modelling of urban noise propagation might be to employ geometrical models in the near field, the radiosity method for mid-range propagation, and models based upon classic diffusion for far field propagation [17].

11. DISCUSSIONS AND CONCLUSIONS

Although much work has been done in research and practice, there is a number of challenges in the simulation of urban sound propagation:

- Better integration is needed between micro-, meso- and macro- scales, perhaps combining different kinds of model in a natural/automatic way, within one software package. This would require researchers and practitioners get together, considering academic as well as practical values in simulation.

- Consider more sound sources. Much work has been done for traffic sources, but very limited work has been done for other sources, especially positive sources.
- Various urban structures should be taken into account.
- The effects of various urban elements, such as street furniture, are important to consider.
- More calculation indices are needed, in addition to simple SPL.
- More validations are needed for various models.

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