

Sound Propagation in Micro-Scale Urban Areas: Simulation and Animation

J. Kang^a, Y. Meng^a and G.J. Brown^b

^a School of Architecture, University of Sheffield, Western Bank, Sheffield S10 2TN, UK, <u>i.kang@shef.ac.uk</u> ^b Department of Computer Science, University of Sheffield, Regent Court, Sheffield S1 4DP, UK

The first part of this paper presents a series of formulae for calculating acoustic indices in micro-scale urban areas, such as an urban street and a square. The acoustic indices include reverberation time and sound pressure level. The formulae are based on both analytic theory and regression of intensive data obtained using two computer simulation models, one based on the radiosity method and the other based on the image source method. The calculations using these formulae and using the computer models are rather close, generally within an accuracy of 10% for reverberation time and 2dB for sound pressure level. The second part of the paper presents a prototype of an acoustic animation tool for urban soundscape design. The intension is to take various urban sound sources into account, as well as their spatial and temporal conditions. The system considers idealised cross-streets and squares, which can be input graphically in a 2D environment. The acoustic characteristics of the urban environment are determined using the above formulae or a database storing results pre-computed by the two computer models. There is also a database of dry signals. With a given receiver and sound signals, the system can produce virtual sound fields with reverberation, and the sound files can be played back in real-time. It is expected that both the formulae and the acoustic animation tool will be useful for urban designers.

1. INTRODUCTION

With the introduction of new EU noise policies [1], noise-mapping software/techniques are being widely used in European cities [2]. While the techniques can provide an overall picture for macro-scale urban areas, to study the sound propagation at a micro-scale – such as an urban street or a square – it would be more appropriate to use detailed acoustic simulation techniques. Several computer simulation models have been developed, and good agreement has been obtained between predictions and measurements [3-5]. However, the current simulation models are still not sufficiently user-friendly, and the computation time is rather long. For urban designers, it would be useful at the design stage to use simple formulae that can estimate the sound propagation in micro-scale urban areas.

In addition to noise prediction and reduction, great attention has been paid in recent years to soundscape research, which concentrates on the interaction between people and the acoustic environment [6,7]. To aid soundscape design, it would be useful to develop a tool that can add acoustic effects to the animation process, taking various urban sound sources into account, as well as their spatial and temporal conditions.

In this research, two computer models have been developed, one based on the radiosity method and the other based on the image source method, for calculating sound propagation in urban streets and squares. Using the models, a series of parametric studies have been carried out. Consequently, empirical formulae have been derived to calculate reverberation and sound distribution in urban spaces. Based on the computer models and the empirical formulae, a prototype of an acoustic animation tool has been developed for urban streets and squares. This paper briefly presents the empirical formulae and the prototype tool.



2. SIMULATION AND FORMULAE

A series of formulae have been developed for calculating the reverberation time (RT), early decay time (EDT) and sound pressure level (SPL), under various boundary conditions. This paper, for the sake of brevity, only presents the formulae for urban squares with diffusely reflecting boundaries.

The formulae are related to the computer model based on the radiosity method. In the model, each urban boundary is divided into a number of small patches, and the sound propagation in an urban area is simulated by the energy exchange between patches [8-11]. The model calculates impulse responses, from which various acoustic indices can be derived, including RT, EDT and SPL. Using the model, a series of parametric studies have been carried out with a wide range of urban square configurations: length L = 20-200m, width W = 20-200m, height H = 5-100m, and square area 400-40000m². The length/width ratio is 1:1 to 4:1, and the side/height ratio \sqrt{LW}/H is =0.5-40. Buildings are considered to be along two, three or four sides of a square, with an absorption coefficient of 0.1-0.9.

It has been shown that with diffusely reflecting boundaries, for an urban square surrounded by buildings with low side/height ratio and low boundary absorption coefficient, the average RT30 using the radiosity simulation is very close to that calculated by the well-known Eyring formula. However, with the increase of side/height ratio and boundary absorption the Eyring formula becomes increasingly inaccurate. Based on theoretical analysis and regression of simulation results, several correction items are introduced. The final form of the reverberation formula is:

$$RT30 = \frac{0.16V}{-SLn(1-\bar{a}) + 4mV} (88.6 + 49a_b + 2.7\frac{\sqrt{LW}}{H})$$
(1)

where *S* is the total surface area and *a* is the average absorption coefficient, both including an imaginary square ceiling. V = LWH, *m* is the air absorption factor, and *a*_b is the average absorption coefficient of boundaries, i.e. façades and ground only. It has been demonstrated that within the configuration range considered, calculations by equation (1) and by the radiosity model are very close, generally within an accuracy of 10-15%.

With a similar procedure as above, a formula for the SPL distribution in a square with diffusely reflecting boundaries has also been derived:

$$L = L_{W} + 10\log(\frac{Q}{4pr^{2}} + \frac{3H}{W+L}\frac{4}{R})$$
(2)

where $R = Sa_T/(1-a_T)$ and $a_T = a + 4mV/S$. L_W is the sound power level of the source, Q is the directivity factor of the source, and r is the source-receiver distance. The difference between calculations using equation (2) and using the radiosity model is generally within 2dB. Equation (2) is inapplicable to long rectangular spaces, where the SPL attenuation is considerably greater than that in quasi-square spaces.



3. DIGITAL AUDIO ANIMATION

To develop a digital audio animation tool for aiding the design process of urban soundscape, the basic requirements include: (1) It should consider various urban sound sources, such as traffic, fountains, street music, construction, human voice and bird singing; (2) It should consider dynamic characteristics of the sources, for example, variation of traffic in a weekday; (3) It should consider the movements of sources and receivers; and (4) The calculation speed should be reasonably fast, so that a designer can adjust the design and then listen to the difference. Existing software, however, is not directly applicable to the above. Programs based on techniques for room acoustics simulation, although producing rather accurate acoustic indices and providing good auralization functions, are time-consuming and less suitable for considering multiple sources with dynamic characteristics. Some noise-mapping programs can provide acoustic animations, but reverberation is normally not considered, and the source conditions are still rather simple. In the virtual reality sector, digital sound rendering techniques are being rapidly developed, but the space configurations and the source situations are rather different from those required in urban soundscape. As a result, to aid urban soundscape design, it is still necessary to develop a simple but practical tool.

In this research such a tool is being developed, where the early part of impulse responses can be simulated by techniques such as ray-tracing, and the late decays are determined using formulae such as those presented in Section 2, or using a database. In the database the results are precomputed using simulation models such as those mentioned in Section 2. In this way, the source location and the spatial effects can be reasonably well simulated, but the calculation time is greatly reduced. In the following sections, a prototype of such a tool is briefly presented.

3.1. The system

The prototype has been developed using Java, an object-oriented programming language. Currently it is for idealised cross-streets and squares, and the reverberation effect is based on the RT rather than simulated impulse responses. The interface of design input is shown in Figure 1. It allows the user to input a design graphically in a 2D environment. Within an area of 200m by 200m, a wide range of street and square dimensions can be given. Buildings are assumed to be continuous along a street or along two or more sides of a square, and of a constant height.

Any number of sources can be selected from a database, which currently includes 20 dry sound samples in .wav, .au or .aiff format. The sources can be put at any position in the streets or the square. There is no limitation for the signal length.

For a given receiver, the system can determine the acoustic indices including RT, EDT and SPL based on a database or formulae, as described in Section 3.2. The system can then produce sound files with appropriate sound level and reverberation, based on the digital audio processing described in Section 3.3. Figure 2 shows the interface for inputting sources and receivers, as well as generating sound files. The calculation and convolution are rather fast - a sound file can be played back immediately after a receiver is given. The original dry signals without the effects of urban environment can also be played back for comparison.

The system is intended to be user-friendly and great attention has been paid to user interaction. A designer can change the configuration, and then listen to the acoustic environment in real-time. A design can be saved for further comparison and presentation. In the system a help function and some initial design guidelines for urban soundscape are also included.



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Figure 1. Interface for design input in the prototype tool for aiding soundscape design.



Figure 2. Interface for inputting sources and receivers and generating sound files.



3.2. Database

For urban streets, a database has been created to store pre-computed acoustic indices, including RT, EDT and SPL. The database is based on simulations using the radiosity model and the image source model as mentioned previously. For urban squares, direct calculation can be made using the simplified formulae as partly presented in Section 2. In the database both diffusely and geometrically reflecting boundaries are considered. Currently the boundary absorption coefficient is assumed to be 0.1 and no air absorption is taken into account.

In the current database the range of street dimensions are: length, 10-200m; width, 5-60m, and height 3-16m. For squares the dimensions correspond to the applicable range of the formulae (see Section 2). The database is still being expanded by considering more configurations and more boundary conditions.

3.3. Digital audio processing

The system renders user selected dry sound signals with the acoustic indices, to simulate the reverberation effects. Conventionally digital audio processing could only be implemented using special digital signal processing (DSP) hardware because of the limitation in computing resources, but the Java sound application programming interface (API) specifies mechanisms for capturing, processing, and playing back audio data in a framework that promotes extensibility and flexibility [12]. It allows full access to the underlying synthesis and the rendering engine without much complicated digital processing code.

A set of unit generators form an audio processing chain (including the special unit that communicates with the audio hardware), allowing the system to read, render and play sound files. These generators, which have been implemented using the Java sound API, encapsulate the use of audio processing at the signal level. The source unit reads the dry signal as a .wav, .au or .aiff file and passes it to the reverb unit. The reverb unit renders the sound via audio-buffers and the sink unit converts those back into audio files.

In this prototype, the implementation of the reverb unit is based on the reverberation algorithms originally developed by Moorer [13-14]. The input signal is filtered through 6 parallel comb filters with a lowpass filter in each loop. Each comb filter is characterised by a feedback coefficient and a delay time, which are related to the space size and the RT. The result of summing the 6 comb filter outputs is fed through two allpass filters, which are again characterised by a feedback coefficient and a loop delay time. The final result is then mixed with the original dry signal.

3.4. Discussion and further work

The tool is still in its initial stage, and substantial development is being carried out. Various digital audio animation methods, from computing full impulse responses to considering a single RT, will be compared through subjective listening tests in a CAVE environment [15], in order to determine a fast but appropriate method. Head-related functions are being integrated to generate virtual acoustic environments with a better spatial impression. More state-of-the-art techniques in virtual reality are also being integrated [16]. General configurations of micro-scale urban areas will be considered in 3D, with the possibility of inputting drawing files from a range of programs commonly used in architectural and urban design. More spatial and dynamic characteristics of the urban sound sources are also being incorporated.



4. CONCLUSIONS

This paper briefly presents the empirical formulae for calculating sound field in micro-scale urban areas like an urban square, and a prototype of an acoustic animation tool for aiding urban soundscape design. The formulae are easy to use and the calculations using these formulae and using the computer simulation models are very close, generally within an accuracy of 10% for reverberation time and 2dB for sound pressure level. The prototype simplifies the simulation process by using a database or the formulae. With a given receiver and dry sound signals, the system can produce virtual sound fields with reverberation in real-time. While the prototype has been proven to be useful for aiding design, substantial further developed is still being carried out.

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