NUMERICAL MODELLING OF SOUND FIELDS WITH MIXED SPECULAR AND DIFFUSE BOUNDARIES USING COMBINED RAY TRACING AND RADIOSITY METHOD

Y Meng University of Sheffield, School of Architecture, Sheffield S10 2TN
J Kang University of Sheffield, School of Architecture, Sheffield S10 2TN
Y Smyrnova University of Sheffield, School of Architecture, Sheffield S10 2TN

1. INTRODUCTION

It has been established that the consideration of the diffuse surface reflection is crucial to acoustic modelling, and must not be neglected. This consideration is of particular importance to urban open space modelling, where building surface irregularities commonly exist [1-3]. The ability to deal with mixed specular and diffuse reflections, in order to make correct simulations, is a difficult task, but it is also the main priority of a good simulation model. In previous research, solutions have been developed by extending the ray tracing method [4-9], and by combining beam tracing with radiosity method [10-11].

Ray tracing is one of the most efficient acoustic modelling methods as it can manage multiple polygons and complex geometrics. While it has often been considered to be computationally expensive, with the increase of computer powers and the development of accelerated technology within other fields like computer graphics, ray tracing can now calculate unlimited reflection orders with a large number of rays in very short time periods, even in real time [12-15].

Ray tracing is more suitable than beam tracing for combining with radiosity method. A possible combined process is to calculate the sound propagation and to store the diffuse energy into each patch it hits, and then the patches can carry out the energy exchange in order to calculate the diffuse reflection. During ray tracing, each ray carries its energy independently, therefore making it easier to store the diffuse energy into patches at each reflection in an efficient manner. Because of the above reasons, a combined ray tracing and radiosity simulation model, CRR, has been developed.

2. MODEL OVERVIEW

The procedure of CRR is illustrated in Figure 1. In order to take advantage of the advanced rendering techniques and the integration of the audio-visual interaction, CRR has been developed based on a computer graphics package – RayTrace [16], for basic geometry model construction and for ray tracing. The state-of-the-art calculation algorithms have been considered through the CRR implementation, which results in a fast and efficient calculation [17]. The user can choose the number of reflection orders, and whether the calculation should include radiosity calculation. The radiosity calculation uses triangles to present the patch and gives the user the flexibility of determining the patch numbers so that the calculation speed and accuracy can be controlled. Multiple sources and receivers can be considered. In brief, CRR is in five distinct phases:

1. Scene modelling. CRR divides the model geometry into a set of patches, assigns the visual and audio properties of the surfaces, and defines the size and location of the sources and receivers. In order to deal with a complex geometrical environment, the geometrical data and visual/acoustic properties of the materials/boundaries are entered into the system, and then stored into an accelerated data structure - kd-tree.
2. Form factor determination, if radiosity calculation is required. Form factor is the value that determines the proportion of radiated energy that leaves from one patch and that arrives at another patch. It is a key element for radiosity.
3. Ray tracing. When a ray reaches a patch, the diffuse energy is stored into the patch. The ray then continues to travel in the reflected direction along with the remaining energy. If the ray hits a receiver, its energy is recorded into the receiver.
4. Radiosity. After ray tracing is finished, the energy exchange between the patches starts.
5. Acoustic indices. Finally, with the energy impulse response calculated, acoustic indicators including SPL, EDT and RT can be obtained. The impulse response can be modified and converted to pressure impulse response for auralisation.

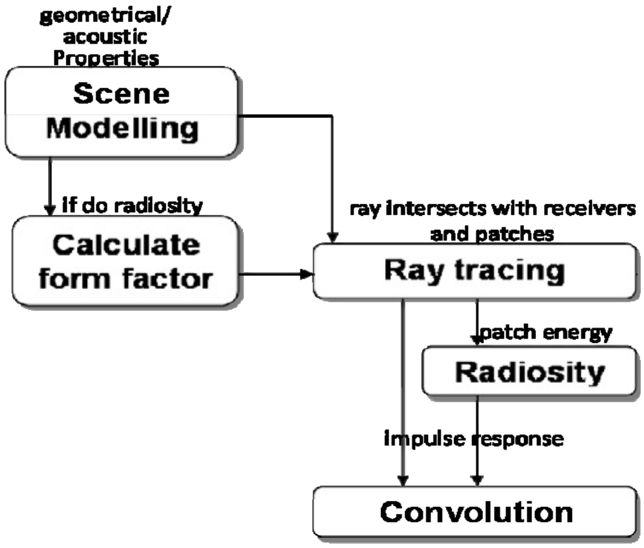

Figure 1. *Calculation procedure of CRR.*

3. COMPARISON WITH OTHER SIMULATION MODELS

CRR has been used to model a hypothetical urban square in order to compare its calculation results with two existing simulation models. Figures 2a to 2c compare the result of SPL, EDT and RT, respectively, as calculated by CRR and an image source model, with boundaries that are considered to be totally specularly reflective for both calculations (diffusion coefficient δ = 0). It can be seen that the agreement is generally good, with the difference of SPL being within 1.6dB, the difference of EDT within 1.30s and the difference of RT within 0.37s. Figures 2a' to 2c' compare the result of SPL, EDT and RT calculated by CRR and a radiosity model, with boundaries that are considered to be totally diffusely reflective for both calculations (δ =1). It can be seen that the agreement between the results is impressive. The difference of SPL is within 1.1dB, the difference of EDT is within 0.30s and the difference of RT is within 0.18s.

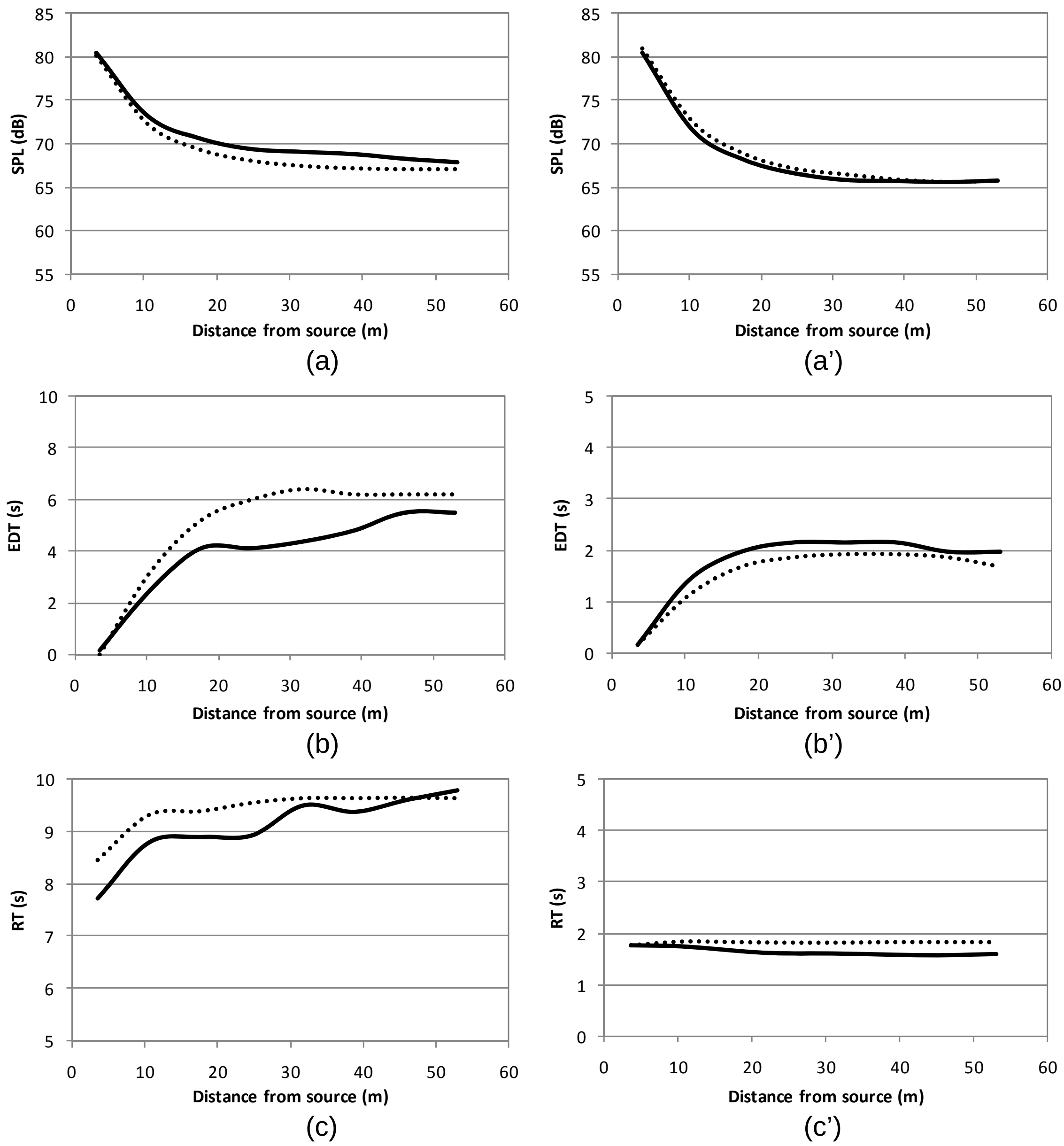

Figure 2. *CRR results compared with other models. (a)-(c) with the image source model for specularly reflective boundaries; (a')-(c') with the radiosity model for diffusely reflective boundaries.*

4. COMPARISON WITH MEASUREMENT IN A COURTYARD

In order to validate the CRR model and to investigate how it performs in a real urban open space simulation, CRR has been assessed by the measurements in the Regent Court, a courtyard in the University of Sheffield. As illustrated in Figure 3, this courtyard is a typical rectangular square, with a size of 35m x 32m, surrounded by buildings with 15m height. There are several different façades in the courtyard, but they are mostly comprised of brick walls, mixed with glass windows. The ground is mostly grass, mixed with pavements of concrete tiles. Four glass panels are located at each corner of the courtyard.

The measurement was performed when background noise was at a low level. The acquisition and analysis system was the 01dB SYMPHONIE dual-channel unit. The sound source was a starting pistol. A single sound source S1 was located at a corner of the Regent Court. Four receivers were positioned along the diagonal line of the courtyard, as illustrated in Figure 3. The source and receivers were placed at a height of 1.5m above the ground. During the experiment, eighteen recordings were collected.

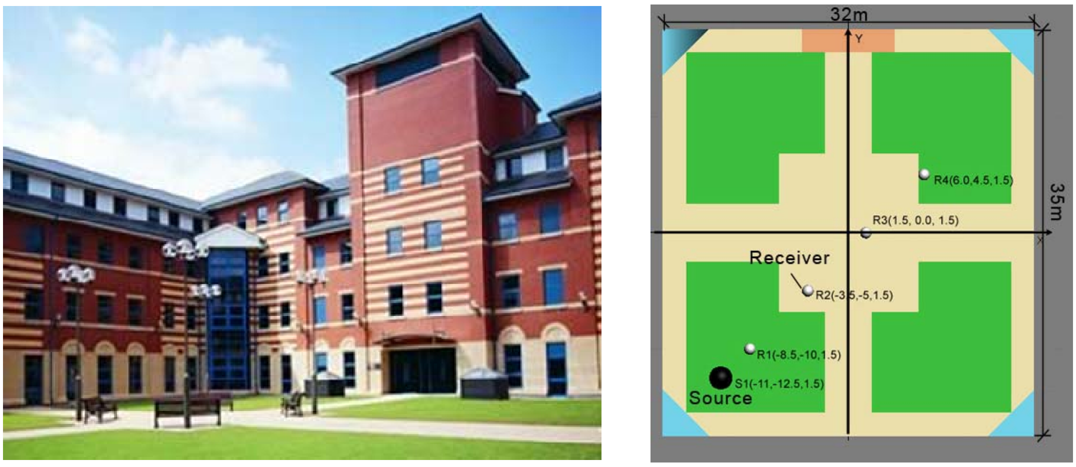

Figure 3. *Inside view and plan of the Regent court.*

Figure 4 shows the comparison between simulation and measurement. From Figure 4a it is seen that the SPL generally decreases with the increase in source-receiver distance. The measured SPL at low frequencies, mainly 125Hz and 250Hz, decreases sharply in the near field, but then shows considerable fluctuations in the relatively far field, say d>10m. This may be caused by the effects of room resonance [18]. Such fluctuations are not shown in the simulated results since CRR is an energy based model. Overall, there is a very good agreement between simulation and measurement, and the average difference in SPL is within 1.1dB. In terms of EDT, Figure 4b shows that the average difference between simulation and measurement is 0.19s, or 15%, at 500-8000Hz. At 125Hz and 250Hz, the average difference between simulation and measurement is 0.85s, or 35.8%. In terms of RT, from Figure 4b it can be seen that, with the exception of 125Hz, CRR provides a rather satisfactory prediction, with an average difference of 0.2s. The relatively large difference at 125Hz, about 0.7s, might again be caused by the room resonance effects, and also the inaccuracy in determining the absorption coefficients of boundaries.

5. EXPERIMENTAL STUDY OF TWO LARGE ATRUIMS

Large atrium spaces are typically found in public buildings. The volume for such spaces is enormous and the surface conditions are usually complicated. In addition, there are often a number of linked or coupled spaces. To further validate the CRR model and in order to examine the reverberation of such spaces, experimental studies have been carried out in two typical atrium spaces. The comparison result shows that, for the first atrium, the CRR model provides a very good RT prediction. For the second atrium, where the sound field tends to be non-diffuse, the prediction with the Sabine formula shows a higher inaccuracy when compared to the CRR model. In both atriums, at individual source-receiver positions, CRR provides more reliable results when compared with the Sabine formula [19].

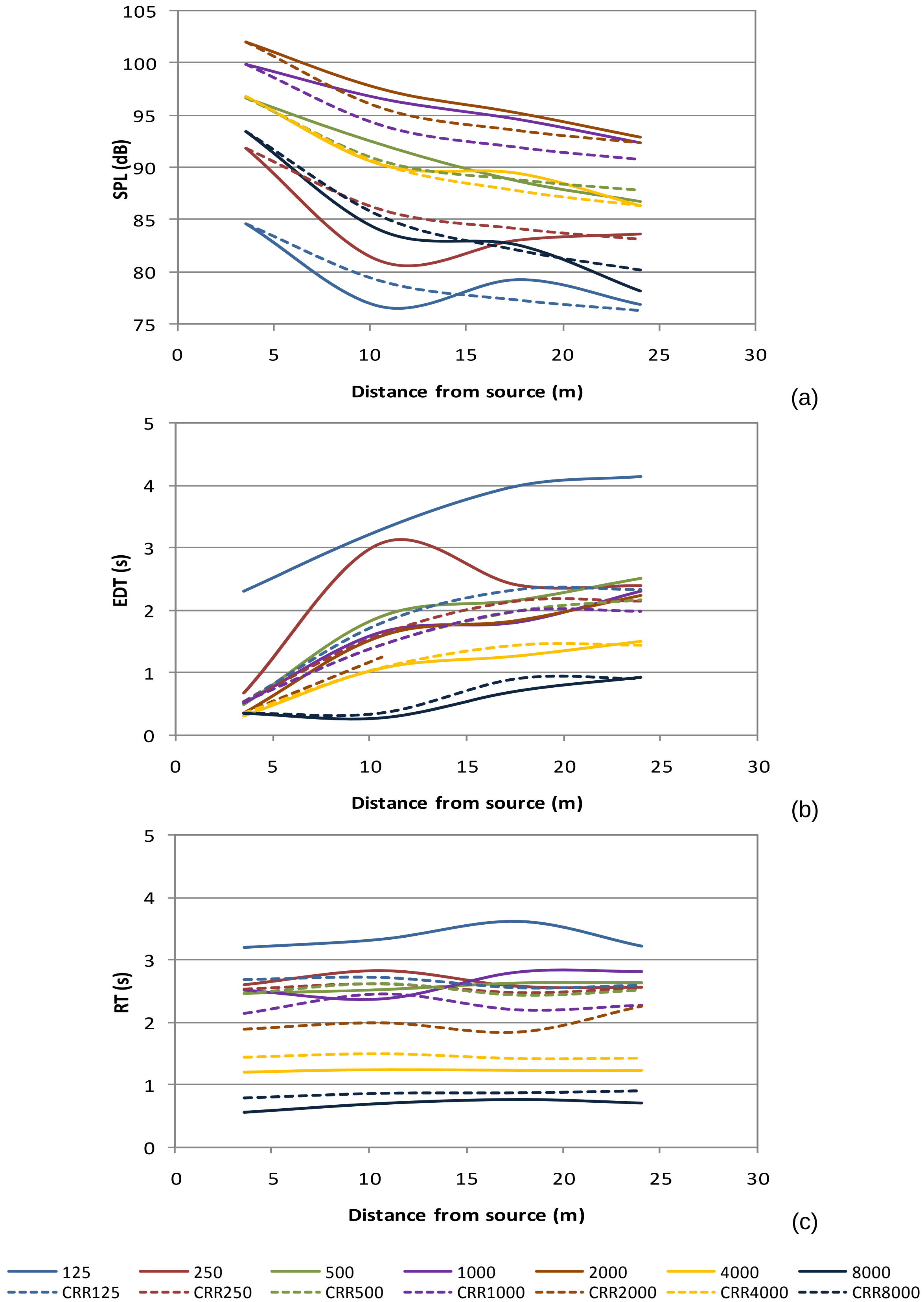

Figure 4. *Comparison between simulated and measured results. (a) SPL; (b) EDT; (c) RT.*

6. CONCLUSIONS

An acoustic simulation model - CRR - has been presented. This model uses combined ray tracing and radiosity to simulate the mixed specular and diffuse reflections. The CRR calculation results have been compared with other simulation models, as well as with measured data in an actual square and two large atriums. It is concluded that the CRR model can reliably predict SPL, EDT and RT. It is noted, however, that at low frequencies typically 125Hz, the inaccuracy is considerable, showing the limitation of energy-based models.

7. REFERENCES

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