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A 3D SOUND PARTICLE MODEL WITH UNCERTAINTY-BASED DIFFRACTION FOR GENERAL GEOMETRIES

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Simulating acoustical environments with sound particles (ray tracing) has been the subject of research for decades. However, current noise standards often rely on simpler algorithms, partly due to difficulties in implementing sound particles in realistic 3D situations, and partly due to open questions on how to implement diffraction. Here we demonstrate a sound particle method that includes "uncertainty-based" diffraction, which represents an improvement over standard "detour" methods. We discuss the handling of a range of practical problems encountered in realistic noise control situations along with efficiency measures. We also present comparisons with wave-based methods.

Keywords: diffraction, geometrical acoustics

1. Introduction

In spite of advances in wave-based simulations, geometrical acoustic techniques remain the preferred method for commercial sound prognoses in room and environmental acoustic situations. However, the neglect of wave physics by the geometrical methods means they have no implicit way of describing diffraction. In the past, this has been dealt with in three ways: if image-source methods are employed, diffraction contributions may be added either through (i) so-called "detour methods" [1] or by using (ii) wave-based approaches along the lines of Biot-Tolstoy-Medwin (BTM) [2]. If ray tracing (sound particle) methods are used, the typical approach is to (iii) ignore diffraction. In the detour case, these methods represent a very rough approximation with known qualitative problems. In the BTM case, the methods are difficult to extend beyond a couple of diffraction events. In the ray tracing "ignore" case, although often acceptable, the results remain hostage to fortune. As Michael Vorländer wrote in his 2008 book on auralization [3]: "Diffraction models and their implementation in image source and ray tracing algorithms will be one of the greatest challenges in future developments of geometric room acoustic simulation methods". Since the mid-1980s, Stephenson and co-workers have built the academic foundations for a form of geometrical diffraction suitable for ray tracing algorithms known as "uncertainty-based" diffraction (see [4, 5] for a review). However, as Vorländer also pointed out in 2008 [3], these ideas had yet to be implemented for general systems.

In this paper we demonstrate an implementation of a sound particle method combined with uncertainty-based diffraction that not only returns improved diffraction results over detour methods in academic cases, but also provides noise maps for more complicated indoor settings on reasonable time scales. We begin by considering two academic noise barrier situations to benchmark the diffraction method, showing it generally lies closer to the wave-based methods prescribed in the Nord2000 standard than the detour methods prescribed by the ISO 9613-2 standard. We then go on to consider an open plan office with a variety of objects, screens and diffracting edges. Hence we show that the method can bridge a long-standing divide and operate usefully in both reverberant situations and ones where diffraction dominates.

2. Methods

Our implementation of Sound Particle Diffraction (SPD) in SoundPLAN software has been detailed in [6]. It follows on from the original recipes of the Stephenson group [4, 5] and works as follows: a point particle cannon launches particles in various directions as specified by the source's directivity. The particle then bounces around the environment according to geometrical rules. On encountering a wall, the particle may reflect (either specularly of diffusely) or transmit. Statistical room scattering is also implemented. Furthermore, for all features that may give rise to diffraction (screening walls or solid corners), we create "virtual walls" that extend from the diffracting edge. On striking such a wall, the particle changes its direction according to a probability distribution, where the probability weighting is controlled by simple formulas derived from Fraunhofer diffraction. Note that in contrast to the original formulation, we do not perform particle splits for diffraction and diffuse reflection, preferring to adopt a statistical approach with random numbers.

Detection of sound particles is done through finite-sized receivers. Every deflection is checked for possible intersections with receivers and the amount of energy deposited is proportional to the crossing length. Air absorption is taken into account at this point.

The insertion of virtual walls is done as part of a three-dimensional convex decomposition of the situation's geometry. Subdividing the polygons into convex volumes conveys performance advantages since it reduces the number of surfaces that must be searched for a particle's next strike, as well as reducing the number of receivers that must be checked for intersection.

3. Screening situations

We begin by considering two screening situations, sketched in Fig. 1, which are designed to probe the limits of existing methods. They contain a single spherically homogeneous source (red circle) and a line of receivers (blue circles), which are either singly or doubly screened from each other. The source operates at 500 Hz and 100 dB sound power. In the first case, (a), the sound diffracts over a box with a lid. In the second, sound diffracts over three diffraction walls with the walls separated to provide equivalent width to the box. In both cases, all walls are perfectly reflecting and there are

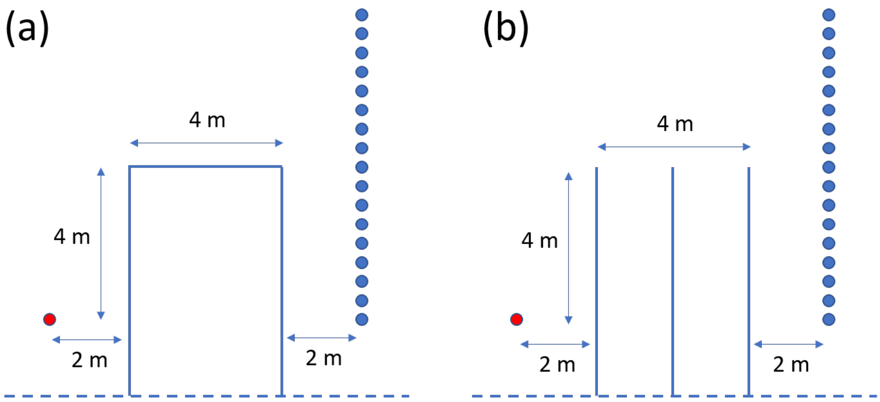

Figure 1: Schematic diagrams (not to scale) of two screening situations. Panel (a) shows screening by a box, panel (b) shows screening by three thin walls. Solid lines represent the (perfectly reflecting) barrier walls, dashed line shows the (non-reflecting) ground. Red circles represent the source (500 Hz, 100 dB) and blue circles are the receivers (0.2 m radius).

no other reflections from any surface, including the ground. We calculate the screening (insertion) effect by calculating sound levels with and without the screening walls and taking the difference. The results for the box and the three walls are plotted in Figs. 2 and 3 respectively.

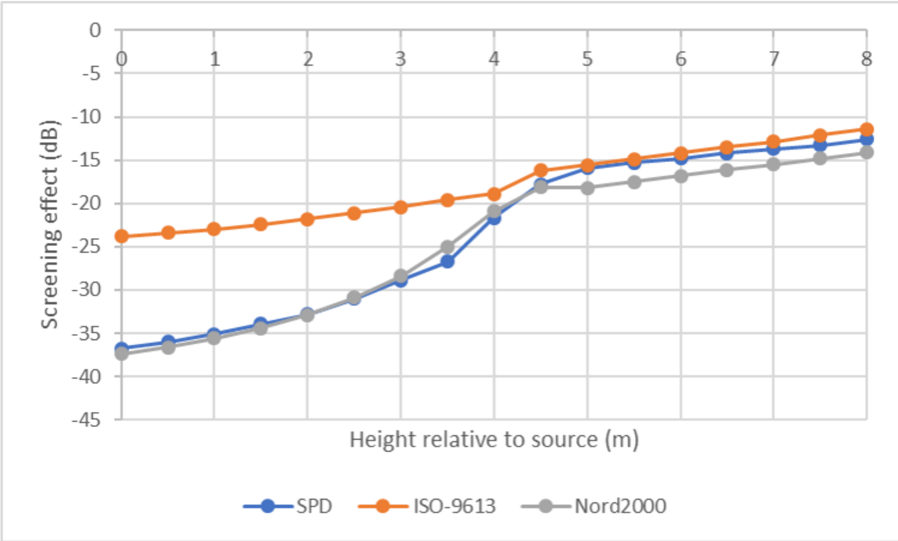

Figure 2: Screening effect against receiver position for diffraction around the box shown in Fig. 1(a). Blue curve shows the sound particle diffraction results, orange curve show the ISO 9613-2 results and the grey curve shows the Nord2000 results.

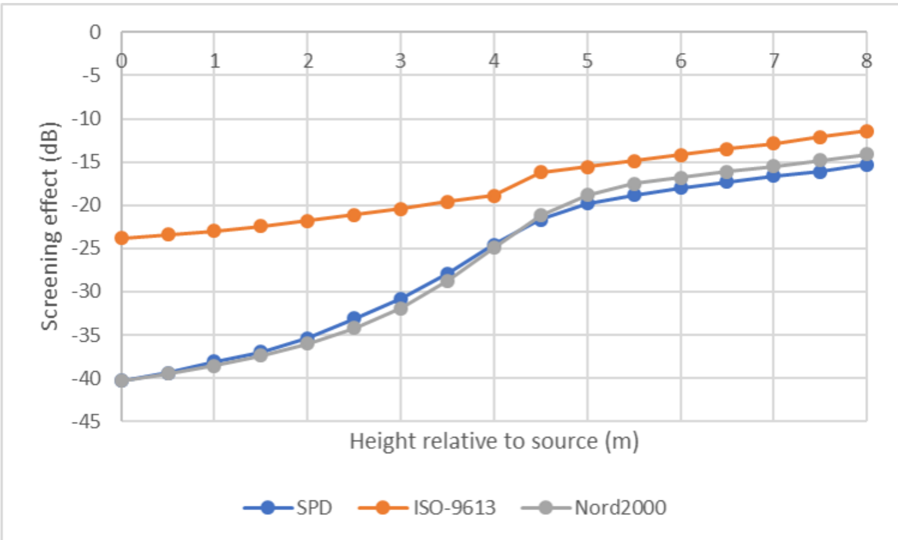

Figure 3: Screening effect against receiver position for diffraction around the triple noise barrier shown in Fig. 1(b). Blue curve shows the sound particle diffraction results, orange curve show the ISO 9613-2 results and the grey curve shows the Nord2000 results.

The results highlight how the ISO 9613-2 methods do not distinguish between the situations - these methods consider only the change of path length required to make a tight detour around the obstacles, relative to the direct source-receiver path. The detour methods take into account whether or not the geometric detour path bends once or multiple times, and use different formulas accordingly. This explains the discontinuity in the results as the receivers pass from the single sound shadow into the double sound shadow.

The more sophisticated Nord2000 methods do consider whether or not we have a thick box barrier or barriers with no "top" and the results vary between the two situations. SPD results generally lie closer to the Nord2000 results, indicating that this diffraction model offers improvements over the detour methods. As with Nord2000, more sound is transmitted in the box case - the gaps between the walls in the three-wall case act as energy sinks here. It should be remembered that the Nord2000 only applies the wave-based method to the two most important diffraction edges. It may therefore be less suited to situations with many diffraction events.

4. An open plan office

Having considered SPD in simple situations so that the diffraction can be compared in isolation, we now consider a more complicated situation to demonstrate that the method can be usefully extended to general geometries. The situation takes the form of a non-trivial open plan office, shown in Fig. 4. The situation shows a variety of features including a non-convex floor plan, screening walls,

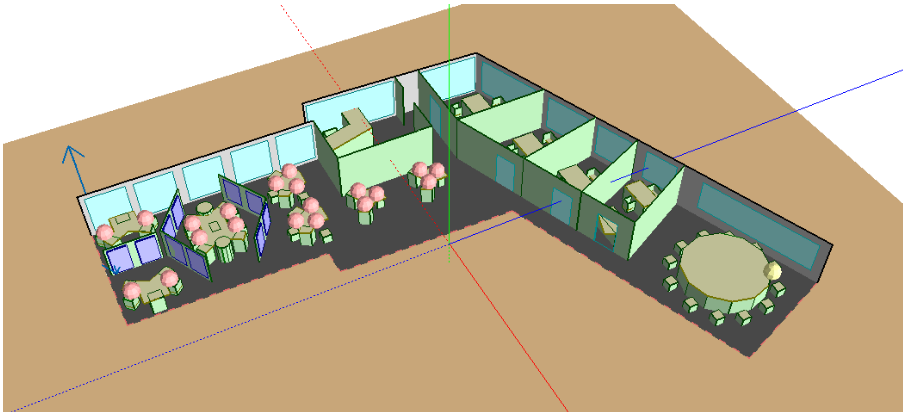

Figure 4: Representative image of an open plan office, used for subsequent results. Pink spheres represent the position of sources. Green surfaces are internal walls/surfaces, dark blue surfaces are absorbing wall patches, light blue areas are windows.

enclosed offices, desks, cylindrical furniture elements, chairs, filing cabinets, sonically translucent doors, a range of absorbing surfaces and a round conference table. In addition, we have placed 20 sources to represent office workers on the chairs in the open plan section of the office. The sources all have an approximate human voice spectrum and a sound power of 70 dB(A).

To provide some insight into how SPD identifies potential diffraction points, we show an image of the office following convex decomposition to show how the virtual walls were inserted (Fig. 5). The

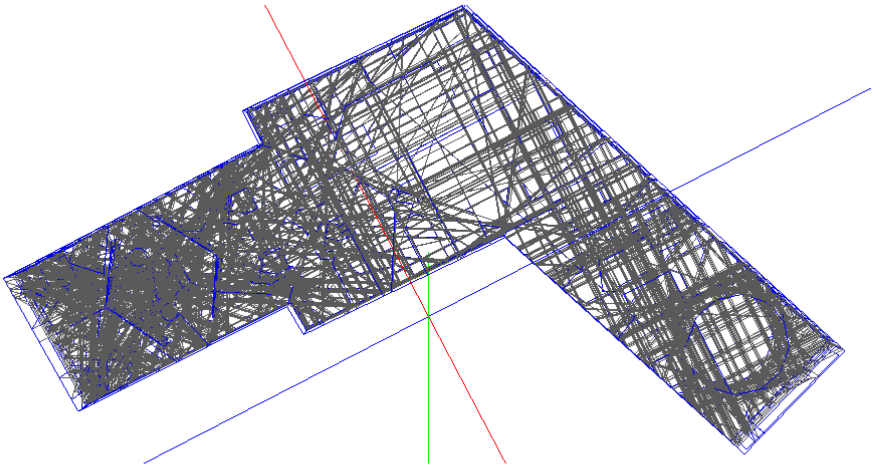

Figure 5: Overhead view of the open plan office in Fig. 4 showing the insertion of virtual walls (grey). “Real” walls are blue.

situation here had 32,591 convex rooms following the decomposition. It is worth noting that while some mathematical applications seek a convex decomposition with as few rooms as possible, this is not the case here, we are more interested in inserting appropriate diffraction walls. For this reason we typically extend “flags” out from all diffracting edges. This increases the number of decomposition bisections but ensures that diffraction zones are not inappropriately truncated by the process.

We show the noise map for the open plan office in Fig. 6. In the areas that can be reached either

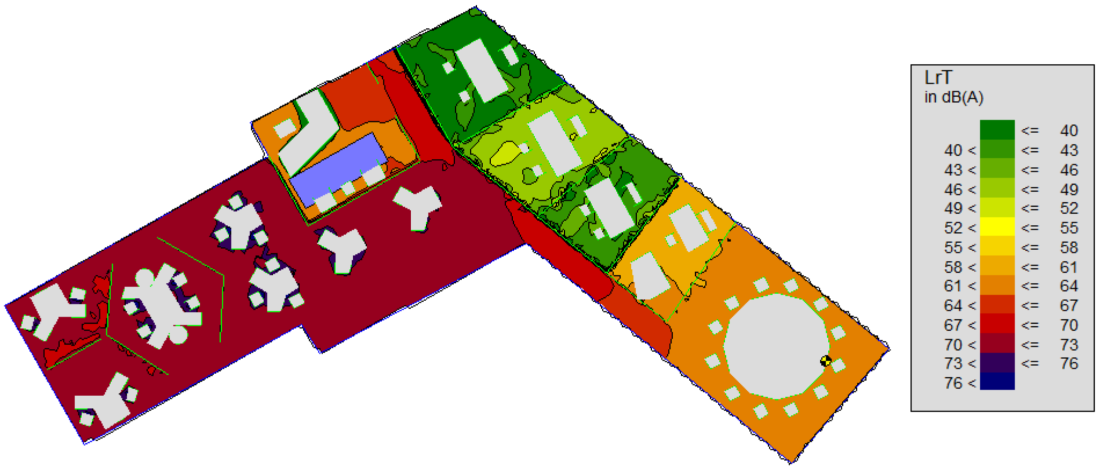

Figure 6: Noise map for the open plan office shown in Fig. 4.

by direct sound or via reflections, we see a fairly smooth and flat sound field. Because we have a sound particle method here, we can simulate dozens of reflections with greater convenience than an image-source method. Sharp drops in the field can be seen within the enclosed offices where sound must arrive by transmission through the doors and walls. In the case of the last office on the right, we simulated an open door, and the sound level is correspondingly higher. This simulation took on the order of an hour to run on a modern laptop PC.

5. Conclusions

We have demonstrated a method of sound propagation that we believe rises to Vorländer’s challenge for diffraction models in geometrical acoustics. The method models diffraction in a way that is closer to wave-based methods than detour methods and avoids non-physical effects seen in the latter. We have shown that it is possible to build on the work of the Stephenson group to create an implementation that can work well for general geometries of interest in room acoustics. With increasing computer power, and further knowledge through ongoing research, it makes sense to review the compromise between acceptable accuracy and acceptable computation time in room and environmental acoustics; we believe the SPD method can help take this debate forward.

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