Increasing the efficiency of beam tracing for noise mapping

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Abstract—**Constructing noise maps for large urban areas is a CPU intensive task, even if engineering approximations to outdoor sound propagation models are introduced. This poster will report on efforts to optimize beam tracing in order to reduce the number of generated paths between sound source and receiver, while maintaining good accuracy.**

Beam tracing is a ray based technique that groups rays in spatial coherent beams. It allows to compute object precise visibility sets, but has as disadvantage of being inefficient in sparse outdoor environments.

Path termination is added to the beam tracer to stochastically terminate beams that travel over great distance. In this way, the algorithm gradually turns into a Monte Carlo ray tracer while it propagates through the environment, increasing the time performance.

An adaptive noise filter is used to reduce the high variance of the result. It distributes energy of highly weighted beams to receivers in the neighbourhood.

Keywords—**Acoustics, Beam Tracing, Monte Carlo**

I. INTRODUCTION

Environmental noise caused by traffic, industrial activities and recreation forms an increasing threat to public health. Policy makers try to turn the tide by enacting stricter regulations. This requires reliable tools to analyse and predict the impact of noise sources on the environment. In case of traffic noise, computational methods to construct noise maps of large areas are CPU intensive, even if engineering approximations are applied. In my PhD work, I've developed an optimization of beam tracing in order to reduce the number of generated paths between source and observer, while maintaining good accuracy.

II. PORTAL BASED BEAM TRACING

Beam tracing [1], [2], [3] is a ray tracing based technique, making the same high frequent approximation, exploiting the spatial coherence of rays by bundling them in beams. From the source, beams are emitted as a set of an infinite number of rays sharing the same source. These beams are traced through the environment until a receiver is hit. Subsequently, a piecewise linear path is constructed connecting source and receiver, and the acoustical contribution of the path is calculated.

The environment is represented by a convex cell complex consisting of linked polyhedral cells. Boundary polygons – which are called *portals* – are fully shared by two cells or not shared at all. Beams can only travel from one cell to another through a portal. The algorithm starts by emitting an omni directional beam for each source. In the originating cell, new beams are constructed for each portal and continued on the other side. A Sutherland-Hodgeman clipper limits the beams to the rays going through the portal. For each new beam, this is repeated recursively and depth-first until a stopping criterion is reached. No approximation of the available geometry is made, resulting in a guarantee of finding all sound paths up to a given number of reflections and diffractions.

III. RUSSIAN ROULETTE

Due to its nature, portal based beam tracing is known to be very easy and efficient for architectural indoor scenes and street canyons. But when it is applied to sparsely occluded environments over an undulating terrain, the number of portals grows rapidly. This causes unnecessary clipping and fragmentation of the beams while the number of paths remains low. The beam tracer becomes a major bottleneck. To avoid this, a Russian roulette [4] is applied in order to gradually reduce the number of beams further away from the source.

At depth N of the recursive algorithm, each new beam is subjected to the roulette. A random number x is drawn from the uniform distribution $[0, 1)$ and compared to a rejection ratio ρ. If $x < \rho$, the beam is rejected. Otherwise, the beam survives and recursion continues. Using this scheme, only a fraction $(1 - \rho)^N$ of the original beams remain at recursion depth N. With $\rho = 10\%$ and $N = 50$, this is less than 1%, resulting in a greatly increased efficiency.

$$P[\text{survival}] = \mathrm{P}[\mathrm{x} \geq \rho] = 1 - \rho \tag{1}$$

The lost energy of the rejected beams must be compensated for to respect conservation of energy, by weighting the surviving beams with a factor $W = \frac{1}{1-\rho}$. The actual energy contribution of the beam becomes Q_k where Q is the original beam energy density:

$$Q_k = s_k W Q = \frac{s_k}{1-\rho} Q \text{ with } \left\{ \begin{array}{ll} s_k = 0 & \Leftrightarrow x < \rho \\ s_k = 1 & \Leftrightarrow x \geq \rho \end{array} \right. \tag{2}$$

IV. ADAPTIVE NOISE REDUCTION

Since the Russian roulette is applied at every recursion level, the beam weight grows exponentially, concentrating all energy in a few beams. Large local errors can be expected ($W = 22dB$ with $\rho = 10\%$ and $N = 50$), reflecting in high spatial variances in the resulting noise maps. Adequate filtering is mandotary.

The extent of the adaptive filter depends on W. Paths with $W = 1$ have not passed the roulette yet and don't need filtering. Paths with $W > 1$ contain more energy than they should, and this will be spatially spreaded over an area proportional to W. In case all receivers lay on a uniform grid, the filter is easily implemented by searching the W nearest neighbours to the receiver, including itself, and assigning the unscaled contribution Q to each of them.

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In the general case however, care must be taken to take in account the *area of influence* A of each receiver, which is the area of the Voronoi cells constructed on the receivers. First, the total contributed energy E is determined by the beam energy density Q, the path weight W and the area of the receiver being hit A_h: $E = QWA_h$. In a circular neighbourhood, receivers are found until their total area is proportional to W: $\sum_i A_i = cW$ where c is an arbitrary constant for the simulation. Finally, E is uniformely distributed over the found receivers:

$$Q_{distributed} = \frac{E}{\sum_i A_i} = \frac{QWA_h}{\sum_i A_i} \tag{3}$$

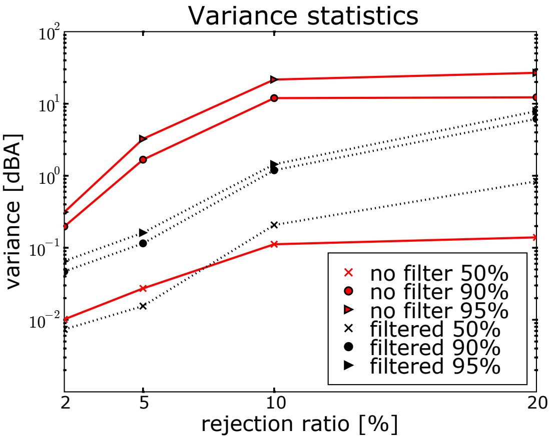

Fig. 1. Variance as function of rejection ratio

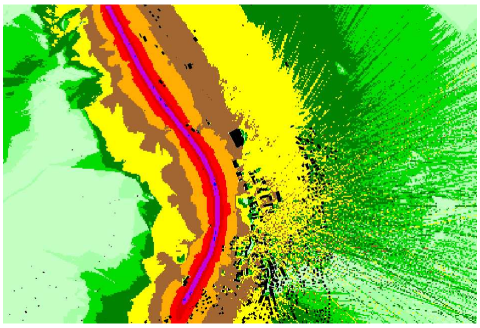

Fig. 2. Noise map without adaptive noise reduction

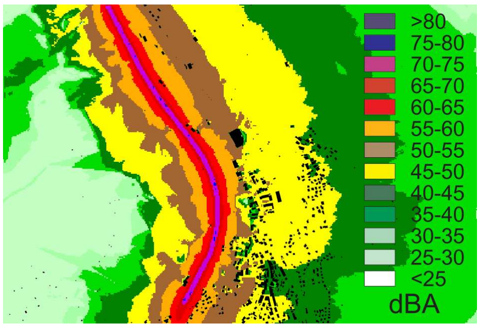

Fig. 3. Noise map with adaptive noise reduction

V. APPLICATIONS AND RESULTS

A. *Variance statistics*

The variance at a location in the noise map is defined as the variance over different runs, the only difference being the random seed. Figure 1 shows percentiles of the variance distribution over the map, used as a single value measures for the quality of the simulation. The 90th and 95th percentiles are measures for the largest errors, while the 50th percentile is an indication on the expected average variance. As expected, the variance increases with ρ. The adaptive noise filtering reduces the 90th and 95th percentiles by almost a decade while the effect on the 50th is less pronounced. It are however the high errors that needs most reduction as they produce large artifacts in the noise maps. Figure 2 and Figure 3 shows the effect of the adaptive noise reduction on the resulting noise map, resolution is 10 m, $\rho = 10\%$.

B. *Performance*

The algorithm delivers an enormous reduction of generated sound paths and a large speedup, but at a cost of introducing variance. There's a tradoff between reducing computation time and maintaining low variance, controlled by ρ. Figure 4 shows the 95th percentile of the variance in function of the computation time for various ρ, for both filtered and unfiltered. The most profitable work point turns out to be $\rho = 5\%$.

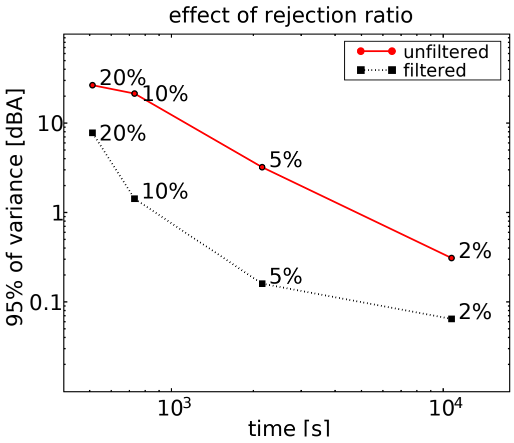

Fig. 4. Tradeoff between variance and time for various ρ, filtered and unfiltered

VI. CONCLUSION

Beam tracing of large sparsely occluded environments suffers from fragmented beams. Russian roulette stochastically eliminiates beams while conserving energy to achieve a large speedup of the algorithm. An adaptive noise filter reduces the noise caused by roulette by redistributing the energy over an area in the vicinity of the hit receiver.

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