Progression Document

Virtual Acoustics - Reuben Thomas

Work Undertaken

The Story So Far

The goal of the project is to write a program which can produce accurate, musical impulse responses of virtual environments, without requiring excessive computation time.

The proposed solution is to write a digital waveguide mesh simulation, which can be used to model the lower range of the spectrum (up to 500-600Hz, for example). This can then be combined with the acoustic ray tracer that I wrote for my undergraduate individual project. Finally, a graphical interface can be written which allows musicians to interact with the software, rather than restricting users to a clunky command-line interface.

I have written a library which allows tetrahedral waveguide meshes to be constructed and executed on the GPU. This means that at each 'step' of the waveguide calculation, many nodes can be updated in parallel, instead of having to update them sequentially on the CPU.

The main research areas that I identified with the waveguide (beyond the parallel implementation) were directional receiver modelling and boundary condition modelling. Of these, I have implemented directional receiver modelling, using the technique put forward by Hacıhabiboglu et al. (2010). Additionally, I have written a short report in which I test the model and compare my findings against those presented in the paper.

I was going to move directly on to boundary condition modelling, but was put off by the density of the papers on the subject. Therefore, I refocussed my efforts, for the time being, on writing a graphical viewer/debugger for the waveguide and ray tracing components. As a byproduct of this, it became apparent that there were some shortcomings in the efficiency of the ray tracer which would require fixing before the project was complete.

Planned Work for the Next Term

Presentation

Annotated Bibliography

Duyne & Smith (1995)

Though not the first paper to discuss 3D digital waveguide meshes (DWM), this is one of the first texts that focuses on the *tetrahedral* mesh. Though less straightforward to implement than the rectilinear DWM, the tetrahedral mesh is arguably better suited for high-performance, low-error applications, as tested by G. R. Campos & Howard (2005) (see below).

Duyne & Smith (1995) put forward a finite difference scheme for the tetrahedral DWM, which is reasonably simple to implement in a digital signal processing (DSP) context. They also prove that this scheme approximates the 3D lossless wave equation, which is not particularly interesting from an implementer's viewpoint, but does at least show that the DWM model is suitable for simulating wave effects such as interference and diffraction.

Finally, a method for calculating the dispersion error of the mesh is given, which is useful in cases where a given maximum dispersion error is required. In such cases, the spatial sampling frequency of the mesh may be reduced until the dispersion error at the top of the output bandwidth is within acceptable limits.

G. R. Campos & Howard (2005)

This paper compares the computational efficiency of several different mesh topologies - rectilinear, tetrahedral, cubic close-packed (CCP), and octahdral. In particular, the dispersion and density characteristics of each topology are measured and compared.

It is shown that the rectilinear mesh has the highest sampling frequency, while the tetrahedral mesh has the lowest. However, the tetrahedral mesh's dispersion properties, alongside its relatively low number of interconnections (and hence calculations) per node mean that for applications where low dispersion error is required (below 22.8%), the tetrahedral topology is the most efficient.

It should be noted that the memory requirements discussed in this paper do not hold true for all mesh implementations. The paper discusses DWMs based on *W-models*, in which each node stores an input and an output variable for each immediately adjacent node. In such meshes, the memory usage obviously scales with the number of interconnections per node, or *coordination number* (so will be low for tetrahedral meshes, which has a coordination number of 4, but will be much higher for CCP meshes, which has a coordination number of 12). However, a linear transformation can be applied to the W-DWM, converting it into an alternate *K-variable* DWM, or K-DWM. This formulation is equivalent to the W-DWM, but requires only a pair of variables to be stored per node, meaning that memory requirements of two K-DWM meshes of equal size and density but different coordination number will be equivalent. For more information on W- and K-DWMs, see Murphy & Beeson (2007).

Hacıhabiboglu et al. (2010)

This paper presents a fast and simple method for modelling direction- and frequency-dependent receivers in the DWM. Such a method might be used to model simple polar-pattern receivers, specific microphones, or even approximate HRTFs.

The method presented requires the node values at the 'output' node and the immediately adjacent nodes to be stored. It uses these values to calculate a velocity vector at the output node for each time-step, and then calculating the 'intensity' at this node. The directional response is found by multiplying the magnitude of the intensity by the squared magnitude of some polar pattern in the direction of the intensity. The output can be split into multiple frequency bands, and a different polar-pattern used per band, if frequency-dependent output is required.

The main draw-back of this method is that its accuracy is dependent on the directional error (not dispersion error!) of the underlying mesh, which is much higher for the tetrahedral mesh (a mean of 8%) than other mesh topologies (which generally have a mean of less than 1% directional error).

Only one other method for modelling directional receivers is presented in the literature (see Southern & Murphy (2007)). The alternate method is similar, but directly compares pressure values at nodes placed (approximately) in axial directions, analogous to the Blumlein microphone technique. The technique also requires very close node spacings, which it achieves by oversampling the mesh, which is very computationally expensive. The method presented by Hacıhabiboglu et al. (2010) is more versatile and much more efficient, so the method by Southern & Murphy (2007) will not be further discussed here.

Murphy & Beeson (2007)

In this paper the equivalence of the K-DWM and W-DWM models is proved, and a method for interfacing between the two models, called the *KW pipe*, is provided. This is useful in cases where the more flexible properties of the W-DWM with respect to frequency-dependent scattering are required, but only over a small portion of the mesh, for example at its boundaries. In these cases, the majority of the mesh can still be modelled using K-DWM nodes, which require much less memory and processing time. It is expected that this method will be used to implement materials and surfaces in the author's own implementation.

Only the 1D and 2D cases are discussed in this paper, but a generalisation to 3 dimensions should be reasonably straight-forward.

Southern, Siltanen, & Savioja (2011)

A method for the combination of room impulse responses (RIRs) generated by different modelling methods into a single *hybrid* RIR is presented.

Geometric modelling methods, such as ray tracing and image-source modelling, model higher frequencies well, but are inaccurate when the sizes of the reflective surfaces are of the same or lower order as the wavelength being modelled. Conversely, the DWM can be made accurate across the entire frequency spectrum, but is too expensive to compute at higher frequencies, as the complexity of the computation increases cubically with the maximum frequency required at the output.

This paper proposes a method which could be used to combine outputs from ray tracing and DWM modelling, producing a RIR which is reasonably accurate across the spectrum, but also not prohibitively expensive to calculate.

Bibliography (and Future Reading)

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