1pAAa9. Energy evolution in enclosure geometries as exhibited by a finite difference time domain method

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Measurements and simulations conducted for the purpose of extracting or constructing impulse responses are inextricably dependent on a limited number of receiver locations. Wave based simulations offer the opportunity to assess an entire evolving sound field. In this work, a finite difference time domain method is implemented to simulate an evolving sound field in a range of enclosure geometries with reflective boundaries. The distribution of energy is monitored statistically, and evidence is presented for the predictability of this evolution based on room geometry alone.

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INTRODUCTION

Room acoustic analysis of unique spaces based on geometry alone, without measurement or simulation, may be possible with a better understanding of the fundamental relationships between the geometries of enclosures and the evolution of sound within. This type of analysis would make use of powerful CAD software, fit neatly into a parametric design framework, and strengthen the bridge between architecture and acoustic design. In this work, a finite difference time domain (FDTD) method is used to monitor the evolution of a sound field within a series of perfectly-reflecting enclosure geometries. Mixing or transition time has been determined via impulse responses, volume-based calculations, and experience [1,2,3,4], but here, specific times are of less interest than insight into the evolution process.

METHOD OF PROCEDURE

Using Rhinoceros 3D

MATLAB was used to carry out the FDTD simulations, chosen for its extensive array of built-in functionality, robustness, and ease of use. However, MATLAB remains primarily a text-based language and is limited in the expression of arbitrary geometries. Much more powerful geometric software is available in design communities. This work uses Rhinoceros 3D because it allows for accurate expression of arbitrary geometries via non-rational uniform bezier splines (NURBS). An open-source plug-in known as Grasshopper, which is a parametric environment that allows geometric systems to be easily manipulated, was used to discretize geometries created in Rhinoceros for import into MATLAB.

Simulating with a Finite Difference Time Domain Method

Finite differences are a class of wave-based numerical methods which can be employed to more accurately model sound evolution than can be accomplished with more common geometrical schemes. This work uses a non-staggered 3D compact explicit scheme on a rectilinear grid - a specific variant known as interpolated wideband [5]. A high spatial resolution of two points per centimeter was used, and simple geometries were chosen. Pressure-release boundaries are utilized, and the source for the simulations is a Gaussian pulse.

To conduct a statistical analysis of energy distribution across the interior of an arbitrary enclosure, a method was developed to identify the region of interior points for any unique geometry. Simply described, a preliminary simulation is begun, and the number of points which have energy values which are perturbed from their initial value is monitored. This number stabilizes when the simulation progresses to an extent that all interior points deviate from their initial values, while exterior points remain at their initial value. The interior points can therefore be easily identified before the primary simulation is begun.

Selecting Geometries

Geometries were designed for this research beginning with a circular enclosure, and continuing steadily away from the circular condition. The centroid is used as a reference point for source placement. The base condition is the circular enclosure with a source located at the center. This condition will never distribute energy evenly since the source will expand, reflect back through the center into another expansion, and reflect again back to its original condition. This cycle will continue indefinitely, and since this is the only condition in which the expanding wavefront is normal to the bounding enclosure everywhere, it is the only condition expected to maintain such a cycle. Thus, the circle with central source is considered a crucial reference point for comparison to the performance of other geometries.

Monitoring Energy Distribution

To monitor the energy distribution across the interior of enclosure geometries, the energy at every calculated point is collected and plotted in a histogram at each time step. The histogram is then checked against an exponential
distribution using the Kolmogorov-Smirnov (KS) statistic. The histogram is rated from 0 to 1, where 1 is an exponential distribution. The evolution of a sound field toward an exponential distribution can thus be monitored.

RESULTS

The circular enclosure with centrally-located source is the base condition of these studies and is expected to be the only condition that continually returns to its initial state in an infinite cycle. The KS statistic evolution shows that the system cycles from very high values to a value that is at lowest about 0.45.

FIGURE 1. KS Statistic analysis of the evolution of sound energy distribution for a circular enclosure with central source.

The following plot shows the evolution of five equal-area geometries according to the KS statistic.

FIGURE 2. KS statistic of the evolution of sound energy distribution for five geometries.

Note that geometries each have their own decays, that they resemble exponential decays, and that all geometries seem to be approaching the same minimum statistic value.
By fitting an exponential curve to each evolution, a unique decay constant can be determined for each geometry. Note that the circular condition will never decay and the greater the perimeter of the enclosure, the faster the decay. It is useful to plot the decay constant for each curve against the difference between the perimeter of the enclosure and the circumference of a circle of equal area.

FIGURE 3. Perimeter difference for eleven geometries.

The further a geometry is from a circle, the quicker it distributes acoustic energy.

In further studies changes to the source location alters the decay constant, indicating that the perimeter difference alone is not sufficient to describe this process. The geometry of the enclosure and the distance from the source to each point on the enclosure might be combined in some way to better predict the evolution of energy.

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REFERENCES