Basics of Computer Acoustic Modeling

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INTRODUCTION

To accurately simulate acoustical phenomena within a computer model, the constraints of the system must be based on reliable, realistic modeling techniques. The construction of the model space and definition of its properties are done with a set of ordered files. The model is then used by different simulation methods to generate a number of acoustical measures and echograms.

THE GEOMETRIC MODEL OF THE ROOM

Initially, a space must be created. This is done with a point, plane system. Points in three dimensional space are defined by a unique corner identification and (x,y,z) coordinates. When three points are defined, a plane can be created. Planes are defined by an ordered list of corner identifications, which create the perimeter. An example of a plane modeled in CATT-Acoustic v7.1e is shown in figure 1. The list of perimeter points must follow the shape of the plane in one continuous direction.

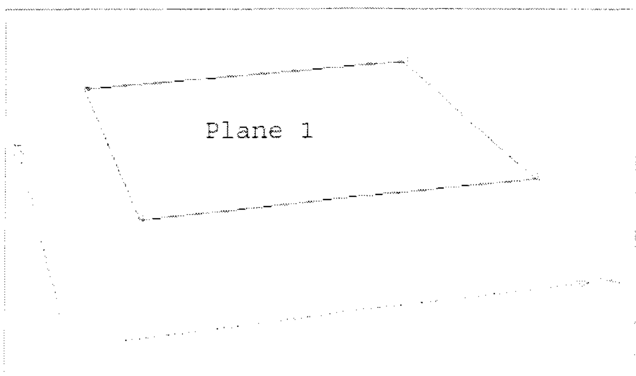

Fig. 1. Sample modeled plane with four vertices

This geometric model data is contained in a geometry file - (*.geo). These geometric specifications for the points and planes, with the other model information, such as absorption and diffusion coefficients, are compiled in a syntax specific, ordered text file. Comments are introduced by a semicolon ";" and blank lines are allowed.

To easily change the dimensions of a model for design studies, variables can be used in the corner identification coordinates, a scaling factor can be applied to each axis, and a mirror function can be used for symmetrical designs. Local and global variables and scaling can apply to one or many *.geo files, respectively. Another way to easily include or exclude parts of a model for comparison purposes is with the include statement which refers to other existing geometry files that can be incorporated in the model. The accuracy of points in complex shapes can be increased with Id(x), Lock( ), and Cut( ) references. These references are used in place of orthogonal coordinates and refer to another point or set of points or planes in the model. Using Id(x) correlates the x, y, or z coordinate to the same as corner "x". Lock ( ) sets the x, y, or z coordinate in the plane of three named points. Cut ( ) sets the x, y, or z coordinate at the intersection of a specified line and plane.

Another way to create *.geo files is through the application that interfaces with AutoCAD. Planes created in the AutoCAD interface are limited to three or four vertices. There are AutoLISP commands useable in AutoCAD after the interface application has linked the two programs. The AutoCAD AutoLISP commands create the *.geo text file. The file can then be further edited exactly like any other *.geo file created within the program.

Acoustic Parameter	Definition
Sound pressure level (SPL)	Sound energy measured in decibels
Strength (G-10)	SPL at 10 m from the source in a free field
Lateral Energy Fraction (LEF)	Ratio of the energy received - lateral:total
Deutlichkeit (D-50)	Fraction of the energy received before and after 50 ms
Clarity (C-80)	Logarithmic ratio of the energy received before and after 80 m
Early Decay Time (EDT)	Decay time evaluated from 0 to -10 dB extrapolated to 60 dB
Rapid Speech Transition Index (RASTI)	Speech intelligibility testing method

Fig. 2.

ACOUSTICAL PROPERTIES OF THE MODEL SURFACES

The next topics to be addressed are the acoustical properties of the materials simulated in the models. The absorption and diffusion coefficients of a material are used to describe the behavior of the modeled surface. The absorption values of a surface are easy to verify experimentally. The sound absorption coefficient (a) of a material is the ratio of the energy absorbed to the total incident energy expressed as a decimal from 0 to 1 for each of the octave bands from 125Hz to 4kHz. The accuracy of the resulting calculations concerning the absorptive characteristics of the hall (reverberation time) can be viewed with confidence. The diffusion properties of any surface are not easily determined experimentally. This is especially true when dealing with the surface texture and rhythm of a surface with a very large area. Therefore the confidence in the diffusion specification is considerably less than with the absorption coefficients. Similarly, the diffusion coefficient (d) of a material is expressed as a decimal from 0 to 1 for each of the octave bands from 125Hz to 4kHz.

The simulated sounds within the model are affected when interacting with the modeled planes. Physical sound waves are represented by rays with specific frequency and amplitude characteristics propagated through the model space. For more accurate simulation of sound wave behavior, the rays are projected as conical shapes into the model. These numeric representations of the surface properties function on the randomized rays or cones that are traced through the space. The absorption coefficients affect the magnitude of the ray in each specific octave band. For example, a 125 Hz ray impacts a surface of concrete, with an absorption coefficient of .01. The reflected ray would have 99% of its original energy after impact. The diffusion is handled differently for the early and late parts of room response. The diffusion coefficient affects the direction and diffuse properties of the reflected energy according to the diffusion coefficient, d. In the early part of the room response, the diffuse reflection order specifies the maximum order that will give diffuse reflection. Diffuse reflection is only given for the last surface in a reflection path. The energy of the ray is diminished by (1-d) for each reflection up to the maximum diffuse reflection order. In the late part, randomizing the reflections of a part of the energy of an incident ray represents the diffusion. Lambert's Law (ideal diffuse reflection) governs the fraction of the incident rays to be diffused. (Kuttruff)

DEFINING THE SOUND SOURCES AND LISTENERS

Sound source and receiver specifications are contained within syntax specific, ordered text files. Sources are defined by a unique identification, the location (x,y,z), the directionality, the aiming direction (x,y,z), the sound pressure level at 1 meter from the source (Lp1m) for the 125Hz to 4kHz octave bands (8kHz and 16kHz octave bands can be specified for full bandwidth auralization), and delay. The delay is represented in milliseconds (ms) and is only used for multiple sources. Receivers are defined by a unique identification number and their location (x,y,z). Multiple receivers and sources can be used within the model. As with the geometric model of the surfaces, variables can be used to easily move a receiver and/or source. The accuracy of points can be increased with Id(x), Lock( ), and Cut( ) references, analogous to the *.geo files.

ACOUSTIC MODELING METHODS

With the geometric model, the acoustical properties of the interior surfaces, and the source and receiver directivity/response defined, the acoustical behavior of the space can be predicted. There are four methods for the prediction of the acoustical response of a space used by CATT-Acoustic v7.1e. The first and simplest is the calculation of reverberation time using the geometric room data and sound absorption coefficients (a). The second is ray tracing. The third is an Image Source Model. The fourth is a complex statistical calculation.

Reverberation time

CATT-Acoustic v7.1e calculates five separate reverberation time (RT) calculations: SabT, EyrT, EyrTg, T-15, and T-30. The SabT calculation is a Sabine RT based on the volume, surface area, and average absorption coefficient. The EyrT and EyrTg are calculations using the Eyring formula (Cremer & Müller). The Sabine or Eyring estimates are only valid in room has very even absorption distribution or are very diffuse (CATT-Acoustic v7.1e Manual). The T-15 and T-30 calculations are straight line least square fits to decay curves at a specific receiver location for 15 and 30 dB of decay.

Ray Tracing

Ray tracing requires a source location and provides audience area mapping of acoustical parameters. The audience areas are defined as planes within the model. These planes are then subdivided into grids. The grid step is variable. A spherical receiver just larger than the grid size is mapped in each square of each audience plane. Audience planes should have the minimum number of vertices and be as close to horizontal as possible. In the ray tracing method, rays are projected from the source into the model. Many rays must be propagated into the model so a suitable number of sound reflections will arrive at each listener location. The number of rays and source directivity can be controlled. The rays project from the source and move through the model space until they strike a wall or ceiling surface. When they strike a surface a portion of the energy is absorbed and the amplitude of the ray is reduced accordingly for absorption at the surface and path length. For specular surfaces, the ray will reflect from the surface according to Snell's Law (angle of incidence = angle of reflection). The direct sound to the audience planes is calculated separately. Diffuse reflections occur at a rate according to the diffusion factor. The direction of the reflected diffuse ray is random. The reflected rays are recorded when they impact on the audience plane grid. The grid within the audience planes is mapped for estimation of acoustic parameters.

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Fig. 2. Acoustic parameters calculated from ray tracing and audience area mapping

Image Source Model

The third prediction method, the Image Source Model, determines all reflections between a source and a receiver. A first order image source is created by calculating the reflection point of the main source in all planes. From each of these first order image sources, a second order is calculated. The second order reflections are adjusted for the absorption and diffusion properties of planes that created them. The process is repeated until the maximum number of reflections or maximum arrival time at a receiver is reached. From these image sources, the three-dimensional travel distance of the sound and its reflections can be translated into the arrival times at a receiver. The amplitude and delay of these arrivals at a receiver point can be translated into an echogram.

Impulse Response

An impulse response is a graphical representation at the amplitude and time of arrival of sounds at a specific receiver location (Siebein & Gold). A free field impulse response

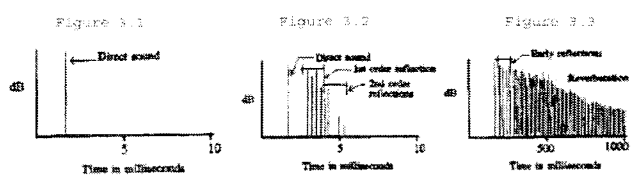

Fig. 3. Sample echograms

illustrates the arrival of the direct sound from the source and the receiver. The time of arrival and amplitude of the direct sound depend on the distance between source and receiver. There are no reflections (no barriers in a free field) arriving at the receiver as in figure 3.1. In an enclosed environment the receiver hears the direct sound as well as reflections. These reflections arrive later and are attenuated as in figure 3.2. In a diffuse, reverberant environment there will be many reflected sounds at the receiver because of the many reflective surfaces as in figure 3.3.

Randomized Tail Corrected Cone Tracing

The fourth and most thorough prediction method is the statistical, full detailed calculation. This algorithmic based method is called Randomized Tail-corrected Cone-tracing (RTC). This method needs fewer settings because it uses the same algorithm for both early and late parts of the echogram. The algorithm conserves computational power by utilizing properties of diffuse reflection rather than calculating the millions of reflections individually. The algorithm also adapts to the acoustical properties of the model and focuses on the early part echogram and on strong reflections.

AURALIZATION

CATT-Acoustic v 7.1e can use the impulse response generated at a specific receiver location together with an anechoic sample sound to synthesize the predicted result of that sound within that space. This simulated sound field is generated using the process of convolution. The two data files, the anechoic *.wav file and the impulse response must have the same sample rate. Convolving the impulse response with the source sound essentially applies the room impulse response to the anechoic sample. Convolution uses a system to mathematically add each reflection from the impulse response to the anechoic sound creating a synthetic reverberance. This new file is a synthesized reverberant sound sample that is based on the acoustical properties of the original model.

CONCLUSION

Computer acoustic modeling provides valuable insight to the acoustical behavior of a space. The use of computer models is cheaper, faster, and more efficient than physical models. The differing prediction methods used in combination accurately predict acoustic parameters. The shortcomings of one method are made up for by the strength of another. Using CATT-Acoustic v7.1e, data can be interpreted in both graphical and tabular forms. Using these predictions, the design of acoustical spaces can be refined and improved without the

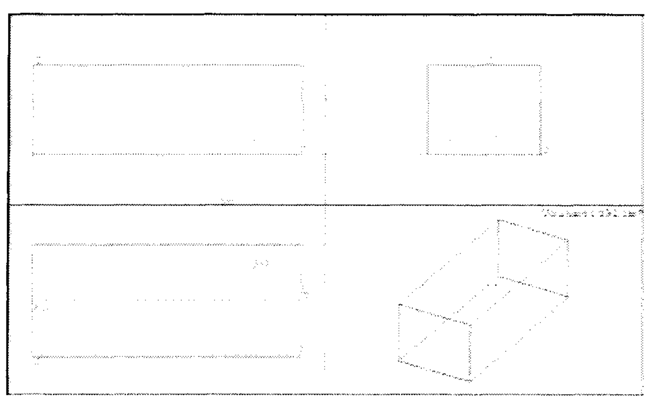

Fig. 4. Example of geometric output

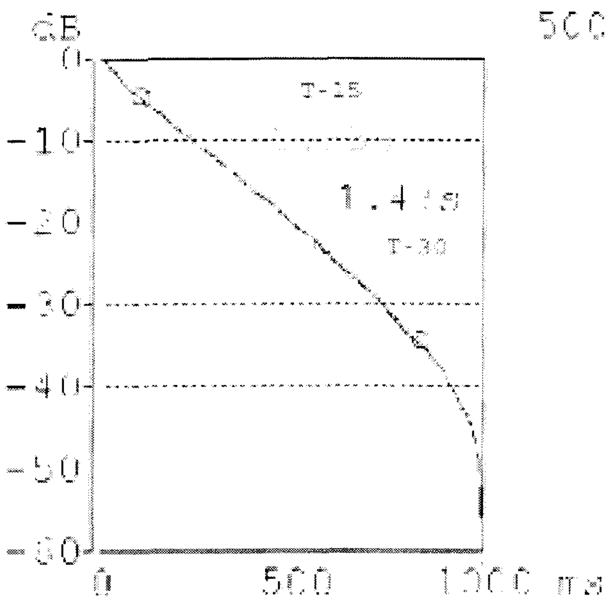

Fig. 5. Example of decay curve graphical output

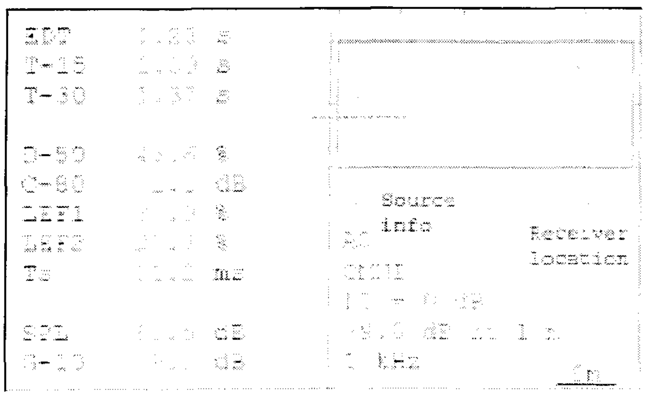

Fig. 6. Example of tabular output

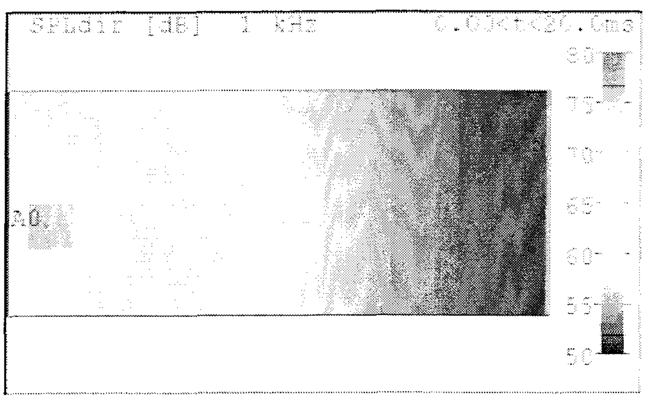

Fig. 7. Example of color specific graphical output for SPL

complications of physical constructions. The insight obtained from accurate computer modeling helps the practical design of any acoustical space.

Sample output of CATT-Acoustic data.

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