BEAM-TRACING METHOD IN NON-HOMOGENEOUS ENVIRONMENTS

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Abstract: The methods for the simulation of propagation of sound based on the principles of geometric acoustics have so far been used in homogenous environments. These methods are based primarily on the reflection, and calculate propagation only in homogenous media. The author in this paper presents alternative method based on the beam-tracing method that can be used to calculate propagation of sound in non-homogenous environments. This method calculates not only reflection, but also the refraction of the sound waves. Also, the scene is not composed from the media and reflective boundaries. This method rather treats all objects in scene equally. All objects are treated as media in which sound propagates, and the discontinuums between objects cause reflection and refraction of sound. This method although more complex than its predecessors is able to calculate propagation of the sound more accurately, and can consider wider range of environments.

Key words: acoustics, computer simulation, beam-tracing

1. INTRODUCTION

Several methods designed for the calculation of propagation of sound exists today [1]. There are two main groups of methods. First one are the simulations based on the principles of geometrical acoustics like virtual source method, ray-tracing, cone and beam tracing. The members of second group are numerical methods like finite element method, finite difference method and boundary element method. These methods have been developed for long time, and presently they are well optimized for specific purposes – the geometrical methods for simulation of indoor acoustics, and numerical methods for simulations of ultrasound transducers. But members of both these groups have severe disadvantages when used for simulation of propagation of sound in non-homogenous environments.

The geometrical methods take into account only reflection, and not refraction, which is a very important phenomena for non-homogenous environments. Also this group of simulations treats only the simple environments with one homogenous media [2].

The numerical methods take into account all wave phenomena, including refractions, and also simulate the non-homogenous media [3]. These simulations cannot work with high order reflections, and also the number of elements used for discretisation of environment sets the limit for higher frequencies. Also, numerical simulations usually work only in 2D due to severe increase in number of discrete elements when environment is treated in 3D.

In order to overcome the shortcomings of these methods, the new method is being developed, that would be able to calculate reflection and refraction of sound (as well as diffuse reflections and diffraction) in complex non-homogenous 3D environment.

2. THE ENHANCED BEAM-TRACING METHOD

The beam-tracing method has been chosen as the basis for the simulation of propagation of sound in non-homogenous environments. The reason for such a choice is the fact that the beam-tracing method (BTM) compiles the spatial coherence (like the virtual source-method) with the speed (similar to ray-tracing method), and the ability to simulate different wave phenomena such as the diffraction and diffuse reflections [4]. The name for the new method is the Enhanced beam-tracing method (EBTM). The goal of this method is to be able to accurately and efficiently simulate the non-homogenous environments. These environments have complex 3D geometry, and are composed of several homogenous and diffuse media.

The new EBTM brings several enhancements to classical BTM. First there is the new scene composition, which is totally different from the approach in ordinary
geometrical simulations. Second, there is ability to simulate propagation in homogenous and diffuse media. Finally, in EBTM, reflections and refractions is treated equally, while in the classic geometrical methods only reflection is taken into account.

2.1 The scene composition

In classic geometric methods, the scene is composed of reflective boundaries, which generate the reflections - the primarily phenomena in these simulations (fig. 1).

![Fig.1. – The structure of the scene in classic geometric simulations](image)

The reflective boundaries can be composed of triangles or polygons, and are 2D objects - their volume is of no consequence, since there is no refraction and propagation behind the boundary.

![Fig.2. – The composition of scene in EBTM.](image)

The EBTM scene composition is showed in fig. 2. The main elements of the scene in EBTM are objects with volume. These objects define the discrete area of a homogenous or diffuse media. The additional elements of the scene are the discontinuum boundaries, which divide two objects. These boundaries are the place where reflection and refraction occur. The reflection causes the return of the beam in the same object, and the refraction transfers the beam into the object on the other side of the discontinuum boundary.

2.2 The object of the scene

There are three types of scene objects in EBTM. The first one is the homogenous object. This kind of object is composed of the material which has the same acoustical characteristics throughout the whole object (fig.3). These are the simplest objects, and the example is the air in the room, the glass of the window etc.

![Fig.3. – The scene composed of two homogenous objects.](image)

Second type of object is the gradient object. Gradient object is not homogenous – the acoustical characteristics are not the same in every part of the media. But important fact is that the change of the media in gradient object is regular, and can be described with mathematical equation. These objects in EBTM are divided in smaller parts, which are small enough that their characteristics can be idealized with homogenous object. In other words, the gradient objects are discretized into smaller homogenous objects (fig.4.). The characteristic of these object is calculated by the mathematical equation. In the algorithm of EBTM, the propagation of sound in the gradient media is calculated in the same way as for the homogenous objects. The examples of this kind of objects are the air in the open space in the summer evening, or the sea water with its temperature gradient.

![Fig.4. – Example of gradient object.](image)

Third and most sophisticated type of object is diffuse object. Same as gradient object, this object have changes in the acoustical characteristics through the volume of the object. But unlike the gradient object, in this case the change is stohactical, and cannot be described with
simple mathematical equation. This media is also divided into smaller homogenous objects. The characteristics of these objects are described with stochastic rules. For every diffuse object, two media with extreme characteristics are defined. The acoustical parameters for smaller, discrete parts of object vary between these two extremes (fig. 5.). The example of this kind of object is the human tissue like the brain tissue, or nonhomogenous geological layers.

The objects of the scene form topological structure which. Two objects, connected with discontinuum boundary form winged-edge structure. This enhances the speed of the algorithm, because the space of the scene is coherently divided into binary-space partitioning tree.

The algorithm

The main parts of the algorithm of the simulation are shown in figure 7.

The first part covers the acquisition of input data. The geometrical data is entered in CAD program and in the form of DXF file loaded into simulation. Also the acoustical data is prepared for every object in the scene, and for the source of the sound. After this simulation enters the preprocessing stage. In this stage the structure of the scene is defined. Objects are logically linked with discontinuum boundaries. The position of source is defined. The acoustical data is linked with all objects and with source of sound. After this process, the computer calculates the BSP-tree for the objects of the scene, and for the TIN networks of the discontinuum boundaries. These preprocessing is made in order to speed-up the main part of the calculation. This is
done by using advanced spatial indexing in the form of the BSP-tree.
The main part of the simulation is the beam tracing stage. This stage is composed of two parts: the generation of initial set of beams and the main loop in which the beams are traced throughout the scene. During the generation of the initial set of beams, the triangular beams are generated in the form of regular polyhedron (fig. 8.). This initial set of beams coherently covers the complete space around the source. These beams are place on the beams processing stack.

![Fig. 8. – Polyhedron used for the generation of initial set of beams.](image)

In the main loop of the simulation the beams are taken from the stack and processed. The collision of beams with the discontinuum boundary is detected. As a result of this collision, two new beams are generated – one reflected from the boundary, and one refracted through the boundary. These new beams are added to stack.

The tracing of particular beam is done until the energy of the beam is lower than the predefined energy level. After one beam is processed, the procedure is repeated until the stack is empty.

The last stage of the simulation is the generation of the results. In this stage for the particular position in the scene the value of amplitude and the phase of the energy of the sound are calculated.

3. CONCLUSION

The enhanced beam tracing method is developed for simulation of non-homogenous environments. Due to their limitations, other methods are not suitable for this purpose. EBTM is based on the beam tracing method, but brings several new features. Scene is composed of objects (volumes) rather than reflection boundaries, and can calculate not only reflections, but also the refraction of the sound. Three types of objects in the scene ensure simulation of complex non-homogenous environments with diffuse materials. The algorithm uses preprocessing in order to create spatial topology of scene, which increases speed of the calculation. The future work on this method would bring the functional software application which would implement the method described in this paper.

REFERENCES