COMPUTER SIMULATION MODEL FOR ROOM DIFFUSE SOUND FIELD

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Abstract: With the development of computer simulation technique for room acoustics, diffuse reflection is considered more and more important. In this paper, some models are developed by considering two diffuse factors in a room-diffuse reflection due to room surfaces and scattering due to objects. The surface diffusion is treated by two different methods on the basis of probability analysis or Energy Conservation Law, and the scattering among objects is simulated as a multiple random ray-tracing process. Thus the sound pressure level distribution in a diffuse sound field can be calculated more precisely and easily. Agreement between the computer simulation results and measurements shows the accuracy of the mathematical and physical model and the applicability of the computer simulation methods. These models can be used in noise control engineering, as well as in the practice of acoustical design.

Key words: diffuse reflection, room sound field, computer simulation

INTRODUCTION

With the development of computer simulation technique for room acoustics, new models have been proposed for more precisely simulating sound fields to realize auralization. The computer has played a very important role in the research on sound propagation, in the prediction of room acoustical property, as well as in the practice of noise control and acoustical design. At present, there are two main methods for describing sound propagation in an enclosed space, namely, ray-tracing model and image source model. But usually these models only consider specular reflection on room surfaces, so their discrepancy from real conditions is considerable. Hodgson (1991) compared computer predictions and measurements in an empty scale-model room, and in various empty factories and gymnasium, and found deviations between predictions and experiments. For improving the prediction, he proposed that there should be 10% - 40% diffuse reflections on the surfaces of the scale-model room, and 60% - 90% diffuse reflections in the empty factories. It can be seen that diffuse reflection is a very important phenomenon that can not be disregarded. Some new models considering diffusion have been proposed recently. One of them describes sound reflection as a process wherein a part of incident sound energy is reflected specularly, and the remainder diffusely. The diffuse reflection is assumed to follow a stochastic process (Kuttruff et al, 1980). Another model assumes that diffuse sound is radiated from diffuse image sources located in an extended range (Dalenback, 1992, Borish, 1984). There are also some methods that combine both ray-tracing and image source models, such as early part image source and late part ray-tracing model (Heinz, 1993), early part hybrid method and late part ray-tracing (Naylor, 1992), etc.

Sound propagation is more complicated in workshops or offices having many machines, equipment and furniture, as the sound waves are not only reflected and absorbed by the wall surfaces, but are also scattered by the objects in them. Sound propagation is then shown as a multiple scattering process. Kuttruff (1991) proposed two factors for increasing the diffuseness of a room: the diffuse reflection on the surfaces and the scattering among objects. This means that the effect of scatterers on sound propagation is also very important. Hodgson (1994) also discussed the importance of these two factors. Leschnik (1980) developed a random ray-tracing model to describe the multiple scattering of noise in urban area. This model only consid-
ered the scattering due to randomly distributed objects, but did not include the reflection and absorption on boundaries.

In this work, some computer simulation models were developed to describe sound propagation in enclosed spaces, by considering the diffuse reflection on room surfaces and the scattering among objects. The surface diffusion is treated by two different methods, and the scattering is simulated as a randomly scattering process.

DIFFUSE REFLECTION ON ROOM SURFACES

In general, reflection on room surfaces can be treated as partial diffuse reflection. This means that a part of the reflected energy is reflected specularly and the remainder diffusely. For describing a diffusing surface, a diffusion factor $d$ is used to account for the fraction of incident energy to be diffused. The relation between absorbed, diffused and specularly reflected energy on the surface is then:

$$a + d(1 - a) + (1 - d)(1 - a) = 1 \ (1)$$

where $a$ is the absorption coefficient.

In computer simulation, a random number $r$ between $(0, 1)$ is first generated. If $r \leq d$, the ray will be reflected diffusely, and if $r > d$, the ray will be reflected specularly. For the specularly reflected ray, the reflection angle is equal to the incident angle. If the incident direction is described by directional angles $(\alpha_0, \beta_0, \gamma_0)$, the reflection direction can be decided from:

$$\cos \alpha_1 = \cos \alpha_0 - 2\cos \theta \cos \alpha_n$$
$$\cos \beta_1 = \cos \beta_0 - 2\cos \theta \cos \beta_n$$
$$\cos \gamma_1 = \cos \gamma_0 - 2\cos \theta \cos \gamma_n \ \ (2)$$

where $\theta$ is the included angle between the incident ray and the normal line of the surface, which can be determined from:

$$\cos \theta = \cos \alpha_0 \cos \alpha_n + \cos \beta_0 \cos \beta_n + \cos \gamma_0 \cos \gamma_n \ \ (3)$$

where $(\alpha_n, \beta_n, \gamma_n)$ are the directional angles of the normal line of the surface.

For the diffuse reflection, we use following two simulation methods:

1. Diffuse reflection according to Lambert Law based on probability analysis

Using Lambert function to treat diffuse reflection is a common method. It can be described as:

$$I_\theta = I_0 \times \cos \theta \ \ (4)$$

where $I_0$ denotes the reflection intensity along the surface normal line, and $I_\theta$ is the intensity along $\theta$ direction, see Fig. 1.

![Fig. 1 Diffuse reflection according to Lambert Law](image)

It can be seen that along the direction of the normal line, the reflection intensity is the strongest, and that the bigger the angle $\theta$, the smaller is the reflection intensity. For a given incident ray, the probability distribution of its reflection direction is not uniform. It would be reflected most probably along the normal line, and as the reflection angle deviated, the probability of being reflected along this angle would be decreased. On the basis of the above analysis, we develop a new simulation method. If the highest probability that a ray is reflected along the surface normal line is $P_0$, the probability that a ray is reflected along angle $\theta_i$ is given by:

$$P_{\theta_i} = P_0 \cos \theta_i \ \ (5)$$

The total probability along all reflection directions should be unity. If we divide the range $[0, \frac{\pi}{2}]$ into $M$ parts, the reflection angle $\theta_i$ may also be described as Eq. (6).

$$\theta_i = \frac{\pi}{2} \times \frac{i}{M} \ (i = 0, 1, 2, \cdots, M) \ \ (6)$$

Since:

$$\sum_{j=0}^{M} P_{\theta_j} = 1 \ \ (7)$$