A REVIEW OF OBJECTIVE DESCRIPTORS FOR SOUND DIFFUSENESS

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INTRODUCTION

Recently, Barron [1] commented that the largest gap in the objective description of concert hall acoustics appears to be the lack of a measure relating to subjective diffuseness or spatial distribution of the reverberant sound. ***The objective of the present study is to review known measurement methods and existing objective descriptors for quantifying sound field diffuseness in an enclosure.*** The *presentation* will address their concepts, merits, shortcomings and potential use. In addition, the concern of where and when "*diffuse*" sound occurs will be explored. Measurements of directional information and their applications for diffuseness quantification employing new objective descriptors proposed and reported by the authors [2,3] will be discussed.

"DIFFUSE" SOUND DEFINITION AND PROPERTIES

A widely accepted definition for sound diffuseness [4,5,6,7] states that a sound field is referred to as "diffuse" when the amplitude of the incident waves are uniformly distributed over all possible directions of incidence i.e. they have equal probability of distribution in all directions and subsequently an equal probability of impinging on the boundary surfaces of the enclosure at any angle. In addition the phases of these arriving waves should be randomly distributed and therefore, their energies can be added. In decaying sound fields these conditions should be fulfilled at each moment of the decay process or over short time intervals compared with the decay process duration.

IMPORTANCE OF "DIFFUSE" SOUND QUANTIFICATION

Sound field diffuseness is considered a crucial condition for the validity of the decay process in an enclosure and subsequently, most of the contemporary room-acoustic indicators are derived on this assumption. In room-acoustics, adequately diffuse sound is desired for acoustical quality. Lack of diffusion may occur due to either simplicity of enclosure geometry or non-uniform distribution of boundary surfaces absorption. Traditional theory for a diffuse space divides the total sound into two components, the direct and reflected sound; the reflected sound is usually subdivided into early and late parts or regimes, the later is then assumed diffuse. Simple diffuse-field theory predicts relatively constant sound pressure levels with increasing source-receiver distance under steady-state conditions and the decay of energy will follow an exponential law. Measurements in existing halls show that the field is unlikely to be diffuse particularly in the late time period. Decay curves are neither exponential nor independent of the receiver position; for large distances from the source however they do approach classical decay theory. Barron [8] developed a revised theory to better explain the variations of sound levels in concert halls, and Hodgson [9] reviewed knowledge about the accuracy and applicability of diffuse-field theory with respect to some acoustical parameters.

Recently, Souldore and Bradley [10] undertook a subjective study on the influence of late arriving energy on spatial impression in a concert hall and found that listener envelopment is produced by late arriving energy as well as early reflections and it is affected by the level and arrival time; surprisingly, since late reverberation is usually considered detrimental to other subjective impressions such as music clarity and definition. The temporal and directional characteristics of the late reverberant reflections required to achieve a certain degree of envelopment however are still unclear.

Since late reflections associated with reverberation affect the subjective judgment of envelopment and diffusion is closely related to reverberation, many questions are raised. For example to what extent should the sound be diffuse and how could this be judged or quantified. Moreover, since diffuse sound conditions are also necessary for many acoustical tests such as absorption measurements in reverberation rooms and transmission loss tests, should qualifying indicators be reconsidered. Methods of enforcing sufficient diffusion in a particular room can neither be decided upon nor their success or failure judged without an objective method and description of diffuseness degree.

KNOWN MEASUREMENT METHODS AND OBJECTIVE DESCRIPTORS

Temporal Diffusion: Sound diffusion has been quantified from the pressure impulse response with respect to time by "Temporal Diffusion", Δ proposed by Kuttruff [4].

$$\Delta = \frac{\Phi_{(0)}}{\Phi_{\max(\tau \neq 0)}} \qquad (1)$$

where,

$$\Phi_{(\tau)} = \int_0^\infty P(t) \,.\, P(t+\tau)\, dt$$

It characterizes the randomness of the impulse response by the ratio of the maximum value of the auto-correlation function of the impulse response, $P(t)$ at zero lag to the maximum value outside the origin.

Spatial Diffusion: A very crude measure based on uniform pressure at all locations in diffuse field is to check the spatial variance of the steady-state sound pressure level at different position in the room excited by random noise.

Another objective descriptor, the directional diffusion index, depends on a knowledge of the sound field directional distribution. Sound directional distribution is characterized by the angles describing incidence (θ and ϕ) at an instant of time. By exciting the room with a stationary sound these parameters can be measured by scanning all directions with a directional microphone of high resolution, then the degree of diffuseness can be quantified by the diffusion index proposed by Thiele **[4,5,6]**:

$$\Theta = 1 - (\mu/\mu_o) \tag{2}$$

where,

$$\mu = \frac{1}{\Omega\langle \hat{f} \rangle} \int | \hat{f} - \langle \hat{f} \rangle | \, d\Omega$$

$<\hat{I}>$ = average intensity, w/m^2, $\hat{I}$ = incoming intensity, w/m^2, Ω = solid angle of interest, and μ_o= μ measured in free field with the same microphone

An indirect but reliable measure is to calculate the correlation coefficient between the steady-state sound pressure signals at different locations in the room expressed by **[4,5]**:

$$\psi = \overline{P_1 P_2} / (\overline{P_1^2} . \overline{P_2^2})^{1/2} \tag{3}$$

Coherence between sound pressure and particle-velocity has been shown to reflect the nature of the sound field **[11]**. Theoretical diffuse field quantification by the two microphone intensity technique has been proposed by Gerges **[12]**, where the coherence function between the acoustic pressure and particle velocity is employed as a quantitative indicator of the sound field diffusion in a reverberant field and defined by:

$$\gamma^2(f) = |G_{pu}|^2 / (G_{pp} . G_{uu}) \tag{4}$$

where, G_{pu} is the cross spectrum of the pressure, $p(t)$ and particle velocity, $v(t)$ signals and G_{pp} and G_{uu} are the auto-spectrum of both respectively.

NEW QUANTIFIERS OF SOUND DIRECTIONAL DISTRIBUTION AND DIFFUSENESS

An ideal diffuse sound field exists when the energy flow at a given position is the same in all directions for all arrival times, hence there is no acoustic net energy flow and the instantaneous sound intensity is zero. Diffusion of the sound field can also be viewed as the sound being isotropic in all direction. In this case the sound decay in all directions should exhibit the same decay rate. Deviation of a directional decay component from the others indicates a lack of spatial homogeneity. Examples of quantifying diffuse sound from the point view of energy flow and directional decay curves will be shown.

CONCLUSION

Objective descriptors of sound field diffuseness exist but both objective and subjective quantifiers require further study. There is also a need for parallel subjective studies to determine the subjectively perceived onset time and required adequate degree of diffuseness that characterizes the late arriving reverberant energy at a listener position.

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