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COMPUTER ANALYSIS OF SOUND DISTRIBUTION IN COUPLED SPACES USING THE RAY TRACING TECHNIQUE

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INTRODUCTION.

Ray tracing is at this moment one of the most popular methods to predict sound distribution in enclosed spaces. However, not much is published about the problems that occur when applying this method to complex spaces. This paper adresses various problems encountered when applying the method to coupled spaces, but will not discuss the specific algorithms.

PROBLEMS ARISING IN THE RAY TRACING TECHNIQUE

Two different types of parameters can be distinguished;

a) Parameters of the ray tracing method: the modeling of the space, the number of rays radiated from the sound source(s), the shape and the dimensions of the receivers of the sound rays.

b) Experimental data: the sound power radiated from the sound source(s), the absorption coefficients of the materials in the room.

Their choice can only be solved by experimental research.

The ray tracing technique was applied to three irregularly shaped spaces:

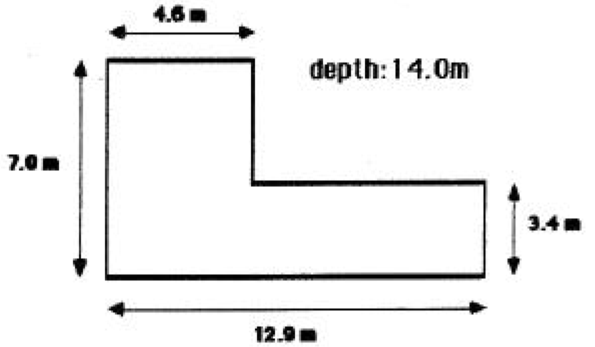
1) a laboratory with: 2 coupled lightly occupied spaces, a volume of 846 m^3, α_S = 0.08.

2) a workshop with: 5 coupled occupied spaces, a volume of 2926 m^3 α_S = 0.23.

3) a corridor with a stairway (3 coupled empty spaces), a volume of 142 m^3, α_S = 0.06.

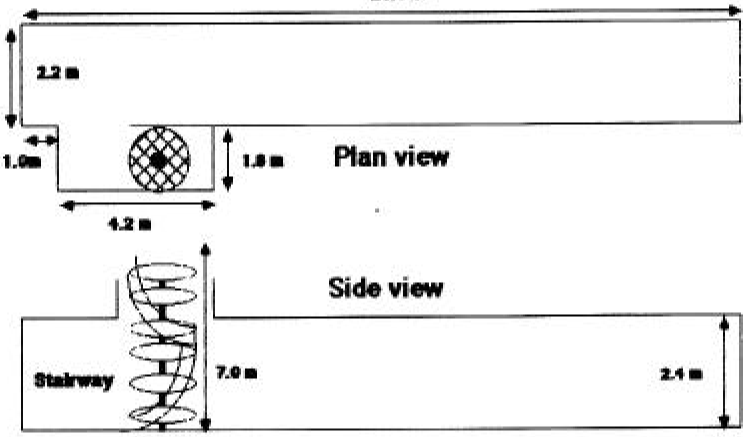
Figures 1 and 2 shows the dimension and the complexity of two of the three spaces. The parameters were tuned by trial and error so that the experimental results fitted best the calculated values.

FIGURE 1: LABORATORY.



Side view of laboratory

FIGURE 2: CORRIDOR.



1. Modeling the Spaces.

It is impossible to fit every detail of a room into a computer program. But if many objects are placed in the room, it becomes very important not to neglect them because they modify the sound distribution. A powerfull preprocessor is needed when this cumbersome task of modeling the space into the computer must be fulfilled. In our case where the objects in the workshop consisted mainly of large machines, a statistical model was not applied, instead the machines were modeled by planes. This did not cause the absolute difference between the measured and calculated values to drop, but the deviation of L_p in all the receptors tended towards the same value of 2.0 dB.

2. The sound power radiated from the source.

In all the tests a B&K 4205 omnidirectional sound source was used, with known sound power levels in the octave bands. In a practical case the user of the ray tracing technique must measure the sound power and the directivity of the sound source considered. It is fundamental that the sound source be well known if accurate results are to be expected.

3. Choice of the receptors.

Table 1 (pp. 4) lists the best results when the receptors are well chosen. Two types of receptors were considered, circles (horizontal) and spheres. The circles seem to yield the best results within the near field (3 m for the B&K 4205). In the reverberant field the circular receptors cause an underestimation of up to -5 dB of the sound pressure level. This problem was solved by using spheres which yield the best results in the reverberant field. The position of the receptors in coupled spaces is very delicate, because in complex geometries it is very hard for the rays to cover the whole volume. Therefore the receptors must be placed in such a way that they are able to intercept rays, possibly after a few reflections.

A diameter of 1 m is to be considered as a good dimension for the spheres and the circles. Small changes in diameter do not seem to influence the results a lot, although "each receptor must receive at least one ray".

4 The absorption coefficients of the materials

Most authors using ray tracing techniques never discuss the origin of the absorption coefficients of the materials applied in their calculations, although the choice of the absorption values is an important matter. Three methods may be used.

4.1 The measured absorption coefficients.

From the measurement of the reverberation time of a room, a mean absorption coefficient can be evaluated with the:

Sabine formula: $T = \frac{V}{6S\alpha}$ or the Eyring-Norris formula: $T = \frac{V}{6S\ln(1-\alpha)}$

with. T. reverberation time (s), V. room volume (m^3). S. total area of the surfaces of the room (m^2), α: Sabine absorption coëfficient (-).
applicable when: $\alpha < 0.3$, the absorption material being equally spread, the room has a cubic shape, the sound field is diffuse.
This method can not be used in the design phase of a room and α calculated with the Sabine formula may be 0.05 (- 10%) higher than if calculated with the Eyring formula.

4.2 The tuned absorption coefficients.
Another method is to adjust the values of absorption coefficients in the computer program in such a way that calculated sound pressure levels fit best with measured sound level values. This can neither be used in the design phase, but it is a good method when an existing space is to be renovated, as it yields the best predictions. However this approach looses total contact with reality.

4.3 Using known absorption coefficients.
A third method is to take listed absorption coefficients from tables. Different problems rise: materials used in the tables are not the same: absorption coefficients measured in different laboratories may differ; various methods other than ISO 354 may be used with sometimes better results; absorption coefficients depend on frequency, temperature, humidity, angle of incidence, etc.
This method can be used in the design phase of a room. However some problems are still to be solved.
Listed values of the absorption coefficients are determined in a reverberation chamber. A model that takes into account the variation of the absorption coefficient with the angle of incidence should be applied. We opted for a technique described by Jacques and Ondet (2) were α_0 is calculated from α_S by the following formula:

$$\alpha_S = 8\frac{(1-\sqrt{1-\alpha_0})^2}{(1+\sqrt{1-\alpha_0})^2}\left(\frac{2}{1-\sqrt{1-\alpha_0}} - \frac{1-\sqrt{1-\alpha_0}}{2} + 2\ln\left(\frac{1-\sqrt{1-\alpha_0}}{2}\right)\right)$$

with α_S: the sabine absorption coefficient, α_0: the zero angle of incidence value,

Then R_0 is determined: $R_0 = \frac{1+\sqrt{1-\alpha_0}}{1-\sqrt{1-\alpha_0}}$

allowing the determination of the angular dependency of the absorption coefficient:

$$\alpha_\theta = \frac{4\,R_0\cos\theta}{(R_0\cos\theta)^2 + 2\,R_0\cos\theta + 1}$$

With this method, in general, the absorption coefficients are at least 0.1 underestimated. A difference of 0.1 in absorption may result in a prediction difference of the sound pressure level of 1.0 dB and a 30% longer calculation time. When adding 0.1 to the listed absorption in the tables the results in table 1 are obtained.

5. The Number of Rays to be Generated and the Threshold Value when to Stop.
Table(1) (pp. 4) lists for the three spaces the best choice for the number of rays to be generated, the threshold value when to stop the tracing, the calculation time on a I.B.M. A.T. p.c. and the mean deviation between the measured and calculated values as defined by:

$$\text{Mean Deviation} = \frac{\Sigma|\text{measurements - calculation}|}{\text{number of measurements}} \text{ in dB.}$$

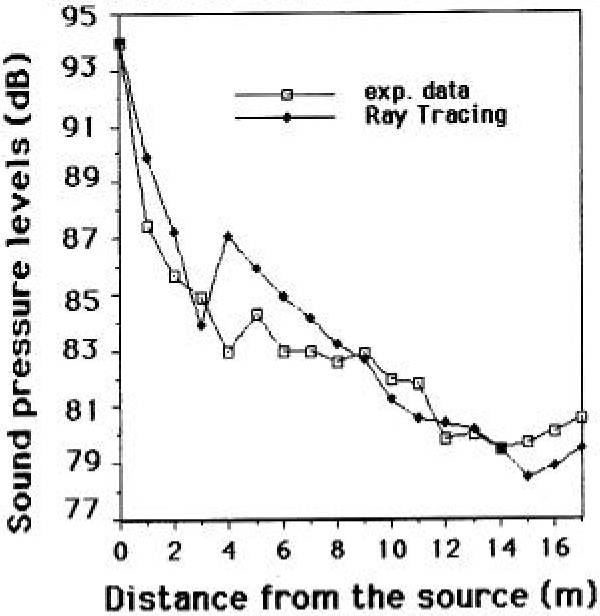
Table 1

Room	Number of rays	Threshold	Mean deviation	Cal. time
1) Workshop:	10000	20 dB	2.0 dB	10 hours
2) Corridor:	6000	30 dB	1.5 dB	6 hours
3) Laboratory:	2000	50 dB	1.0 dB	2 hours

The mean deviation for the different spaces is in all octave bands of the same order as mentioned in table 1. Figure 4 shows for the case of the corridor the sound pressure levels measured and calculated, as a function of the distance r (m) from the sound source.

If more rays are generated better results can be obtained, especially for coupled spaces, because it must be assured that rays fill the whole space. However, only in some locations within the room the calculation will lead to better results. In general the additional computation time needed will refrain oneto generate more rays. Unless a more performing computer is used a compromise between the number of rays and the reliability of the results must be adopted.

FIG. 3 COMPARISION OF RESULTS.



CONCLUSION.

If parameters are well chosen in the ray tracing technique reliable predictions can be made, even if the spaces considered are very complex.

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