Comparison of radiosity and ray-tracing methods for coupled rooms

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In the field of geometrical acoustics, the radiosity method is based on an analogy with the so-called view factor method in thermics. The method has been successfully applied to the prediction of reverberation time as well as the calculation of sound pressure level maps in single room. It has been shown to be equivalent to the ray-tracing technique with diffuse reflection on walls. In this study, the radiosity method is applied to coupled rooms. Transmission and reflection of sound on the separating wall are taken into account by means of Snell's law. Numerical results with the software CeRes are presented and compared with standard ray-tracing. The method is found to be useful for designing enclosures of noise sources.

1. Problems

In industry, the enclosure of sources is a solution frequently applied in order to reduce noise level in industrial rooms. But, before to perform work whose cost may be high with a relative efficiency, it is sometimes desirable to evaluate the reduction in sound pressure level by a numerical approach [1]

The radiosity method has been shown to be equivalent to the ray-tracing technique with diffuse reflection on walls [2], concerning the prediction of reverberation time as well as the calculation of sound pressure level maps in a single room. In this study, we compare results of the radiosity method and ray-tracing technique applied to coupled rooms.

2. The ray-tracing technique

In a simple way, each source is broken up into a large number of rays. All rays has the same power for omni-directional source. The ray power decrease with the source-receiver distance.

The energy density is :

$$W(\vec{r}) = \frac{1}{2}\rho_0|\vec{v}|^2 + \frac{1}{2\rho_0 c^2}|p|^2 \qquad (1)$$

where p is the acoustic pressure and $\vec{v}$ the particular velocity.

Then the Helmholtz equation (2) and the Green function (3) in dimension 3 are :

$$\Delta\Psi + k^2\Psi = -f \qquad (2)$$

$$G(R) = \frac{e^{-ikr}}{4\pi R} \qquad (3)$$

where Ψ is the velocity potential and

k = $\frac{\omega}{c}$

ω : pulsation

c : sound celerity

R : source-receiver distance

$$\vec{v} = grad\ \Psi \qquad (4)$$

we obtain :

$$W(\vec{r}) = \frac{1}{2}\rho_0\ \Psi^2[(ik - \frac{1}{R})^2 - k^2] \qquad (5)$$

While considering R high :

$$W(\vec{r}) = |\frac{e^{-ikR}}{4\pi R}|^2 \quad (6)$$

For the reflections on a wall of absorption "a" and transmission "t" :

(1 - a)*t power transmitted

(1 - a)(1 - t) power reflected

a power absorbed

(1-a) t + (1-a)(1-t) + a =1

Then one computes the power of the rays crossing the surface area of a reception cell.

3. The radiosity method

The objective is to determine the energy density (W) and the energy flow (I)

First : Calculation of direct field

$$div_M\ H(S,M) + mcG(S,M) = \delta_S(M) \qquad (7)$$

Where :

$div_M\ H(S,M)$ represents the crossed power

$mcG(S,M)$ represents the dissipation

$\delta_S(M)$ represents the injected power

In open space :

$$H(S,M) = c * G(S,M)u_{SM} \qquad (8)$$

So

$$G(S,M) = \frac{1}{4\pi c}\frac{e^{-mSM}}{SM^2} \qquad (9)$$

$$H(S,M) = \frac{1}{4\pi}\frac{e^{-mSM}}{SM^2}u_{SM} \quad (10)$$

The second step is to find the complete fields W and I in a domain Ω with boundary δΩ.

With the Helmholtz-Kirchoff formula, fields may be viewed as a superposition of spherical waves created by both actual sources located inside the domain Ω and a source layer located on the boundary δΩ.

So

$$W(M) = \int_\Omega \rho(S)G(S,M)dS + \int_{\delta\Omega}\sigma(P,\theta_P)G(P,M)dP \qquad (11)$$

$$I(M) = \int_\Omega \rho(S)H(S,M)dS + \int_{\delta\Omega}\sigma(P,\theta_P)H(P,M)dP \qquad (12)$$

Where ρ is a magnitude of the actual sources, obviously known, and σ denotes the magnitude of the secondary sources, yet to be determined.

We assume that the directivity does not depend on the point P, so :

$$\sigma(P,\theta_P) = \sigma(P)cos\theta_P \quad (13)$$

This is the law of perfectly diffuse reflection (Lambert's law).

The third step is to develop an equation for secondary sources σ.

The boundary dissipates a part of the incident energy

$$P_{refl} = (1 - \alpha)P_{inc} \quad (14)$$

α : absorption coefficient

$$P_{inc} = [\int_{\Omega} \rho(S)H(S,P)dS + \int_{\delta\Omega} \sigma(Q)cos\theta_Q H(Q,P)dQ].n_p \quad (15)$$

Where n_p is the outward normal vector at point P. The reflected power can now be related to the source magnitude $\sigma(P)$. Consider a small hemisphere HS_ε of radius ε surrounding point P. The power flow crossing this hemisphere is

$$P_{refl}^{\varepsilon} = \sigma(P) \int_{HS_\varepsilon} \frac{e^{-m\varepsilon}}{4\pi\varepsilon^2} cos\,\theta_p dQ = \frac{\sigma(P)}{4} e^{-m\varepsilon} \quad (16)$$

The emitted power at point P is deduced by taking the limit for small ε

The power balance (13) can now be rewritten,

$$\frac{\sigma(P)}{4} = (1 - \alpha)[\int_{\Omega} \rho(S)H(S,P)dS + \int_{\delta\Omega} \sigma(Q)cos\theta_Q H(Q,P)dQ].n_p \quad (17)$$

4. Numerical simulations

4.1 Single room

To begin, we have compared both codes in the case of a single room with diffuse reflection.
The ray-tracing software is “CATT Acoustic” and the radiosity software is “CeReS”.
The objective is to make sure that the software of ray-tracing and that of radiosity gives the same results in the case of an only room before test coupled rooms.
In the first example, length, width and height are respectively equal to L = 10m, l = 5m and h = 3m. The source is located in the corner of the room at position x = 1m, y = 1m, z = 2m, its power is equal to 1W and isotropic. All the receptors are positioned on the plan p = 2m spaced 0.5m. The atmospheric absorption is m = 0.0007m^{-1} which is a typical value at 1000Hz. All surfaces are an absorption’s coefficient a = 0.5 at 1000Hz.
The calculation with CATT Acoustic software was performed with 2000000 rays and a truncation time equal to 5s. The calculation with CeReS software was performed with a mesh of triangles with areas of 0.3m^2. Only the frequency equal 1000Hz is calculated. Results of CATT Acoustic are shown in Fig. 1 and results of CeReS in Fig. 2. The interpolation is realized by Matlab. The difference between 2 simulations is lower than 0.4dB.

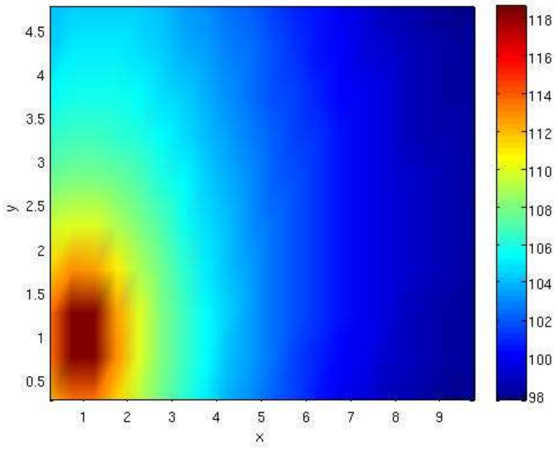

Fig. 1

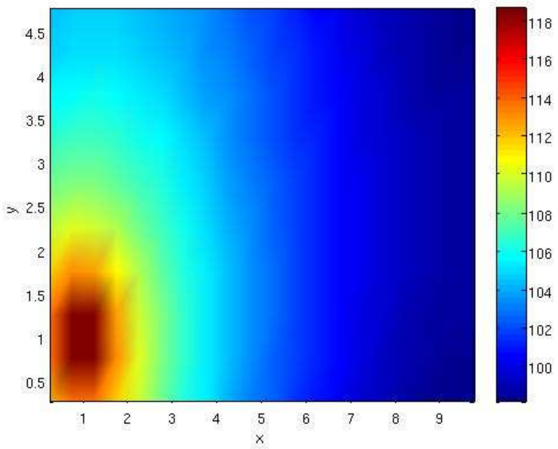

Fig. 2

Next, we added a wall without thickness placed in x = 5m length 2.5m and absorption’s coefficient equal to 0.5. Results of CATT Acoustic are shown in Fig. 3 and results of CeReS in Fig. 4

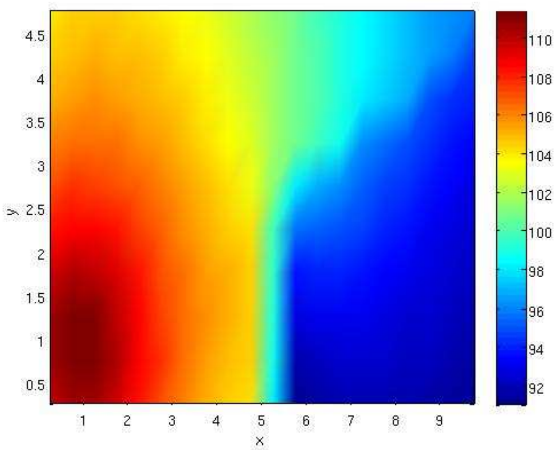

Fig. 3

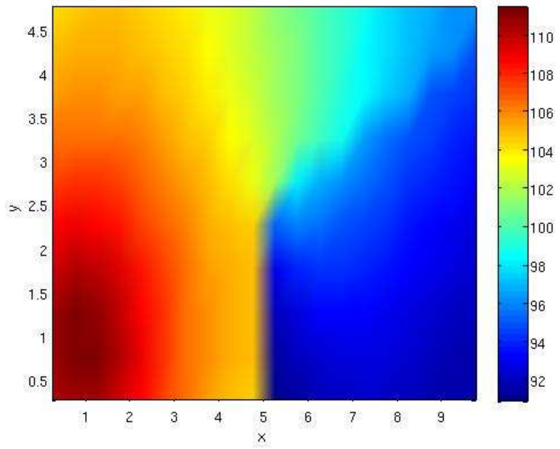

Fig. 4

The difference between 2 simulations is lower than 0.4dB excepted on the receivers located between x = 5.25m y = 0.25m and x = 5.25m y = 2.25m where the difference is bigger.

In the case of singles rooms we will admit that the ray-tracing software and CeReS are equivalent [1]

4.2 Coupled rooms

2 rooms, length, width and height are respectively L = 5m, l = 5m and h = 3m. The coupling is located at x = 5m. The wall being used for the coupling has a density equal to 2000kg/m^3, Young's modulus equal to 20GPa, thickness 0.10m, Poisson's ratio 0.2 and hysteretic damping coefficient equal to 0.05.
The source is located in the corner of the room at position x = 1m, y = 1m, z = 1m, its power is equal to 1W and isotropic. All the receptors are positioned on the plan p = 2m spaced 0.5m. The atmospheric absorption is m = 0.0007m^{-1} which is a typical value at 1000Hz.
The absorption coefficient of the walls is 0.05, of ground 0.01 and ceiling 0.1. The calculation with CeReS software was performed with a mesh of triangles with areas of 1m^2 except for the wall being used for the coupling 0.1m². Only the frequency equal 1000Hz is calculated. Results of CeReS are shown in Fig. 5 for the room 1 and Fig. 6 for the room 2. The interpolation is realized by Matlab. The results show the transmission through the wall.

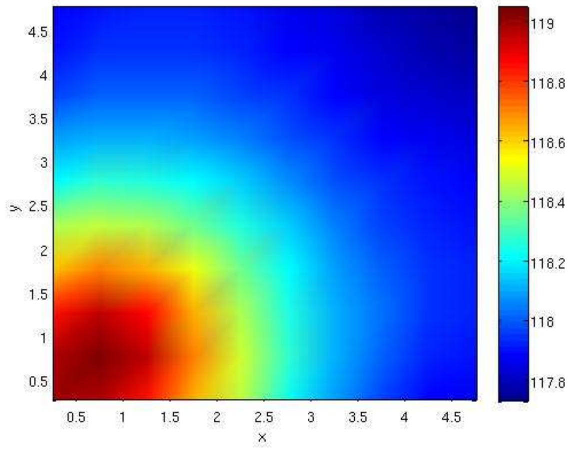

Fig. 5

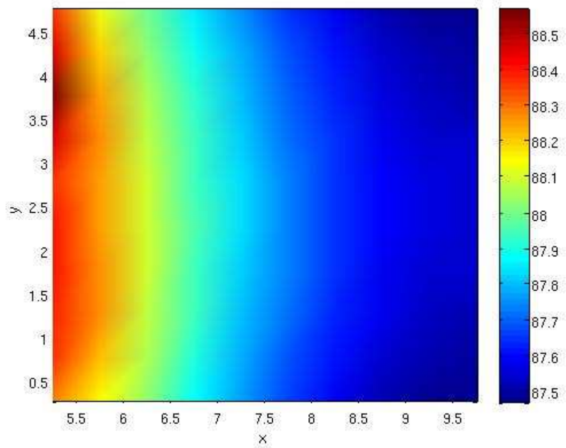

Fig. 6

5. Conclusion

The radiosity method can substituted for ray-tracing in the case of a single room but also in two coupled rooms.

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