RAMSETE - A NEW PYRAMID TRACER FOR MEDIUM AND LARGE SCALE ACOUSTIC PROBLEMS

Angelo Farina

University of Parma, Dep. of Industrial Engineering, Via delle Scienze, 43100 Parma (ITALY)
tel. +39 521 905854 - fax. +39 521 905705 - E-MAIL: farina@aida.eng.unipr.it

INTRODUCTION

The paper introduces a research project called RAMSETE: the goal of the project is to release a completely new computer based system, with the capability to accurately simulate the sound propagation in large rooms and outdoors, taking into account real-world source directivity and extension, specular and diffuse reflections, angle and frequency dependent absorption, excess attenuation, screen shielding. The results of the simulation can be used also for auralization, through a specific true convolutor, that doesn't require specialised hardware but only a standard PC audio board [1].

At the present the development of the project has led to the release of Ramsete 1, that is particularly suited for noise predictions within and outside factories.

The program employees a completely new **pyramid tracer**, that avoids the problems encountered with conical beam tracers (overlapping of cones, multiple detection of the same Image Source).

Besides the particularities of the pyramid tracer, that are discussed in this paper, it must also be noted that the program comes with an innovative Source Manager [2]: it manages the source directivities and sound power data files, and make it possible to automatically define directivity balloons from experimental measurements conducted according to ISO codes 3744 and 3746, with direct reading of the most common R.T.A. file formats. This is particularly important for the noise sources, for which no directivity data are usually collected. However the program easily reads also the loudspeaker directivity data stored in the Bose Modeler (TM) format.

As Ramsete’s target is for industrial noise propagation indoors and outdoors, it is equipped with a large material properties data-base, including absorption coefficient and sound reduction index data: in fact the program takes into account not only the sound energy reflected from the surfaces, but also the quote passing through panels with finite sound reduction index. For the same reason, the program takes into account the energy diffracted from the free edges of each panel (that are automatically located), so that both indoor and outdoor screens can be studied.

The introduction of the geometry is simple, as Ramsete has its own Windows-based 3D CAD, that makes it possible to easily introduce also the sound sources, the receivers and the surface materials. However it is compatible with Autocad (TM), as it reads and writes DXF files.

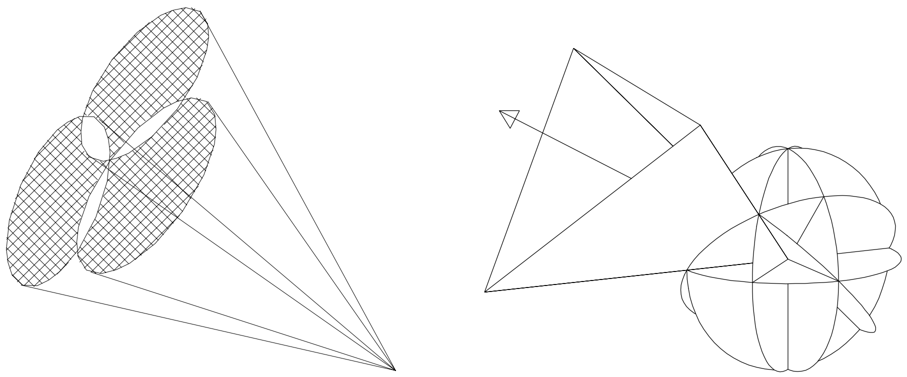
A brief mention need to be made also for the post-processing tools: these include calculation of standard acoustic quantities (Sound Level, Reverberation Time, Center Time, Clarity, STI, LE, LF), with graphical and tabular representation, and a 3D rendering subprogram, that can be used to produce colour or contour maps of the calculated data.

Another post-processing program converts the calculated energy impulse responses in Pressure Responses, that are then convoluted with anechoic signals to produce virtual acoustic listening samples of the calculation results, without the need of expensive hardware tools [1].

In the following paragraphs the Pyramid Tracing theory is explained, and a large effort is made to make it understandable: in fact correct calculations can be done with Ramsete in non-Sabinian cases (as almost industrial noise problems are) only with a deep knowledge of the theory. In these cases the Pyramid Tracing make it possible to obtain reasonably accurate results with computations times that are less than 1/100th of that required with Ray Tracing programs.

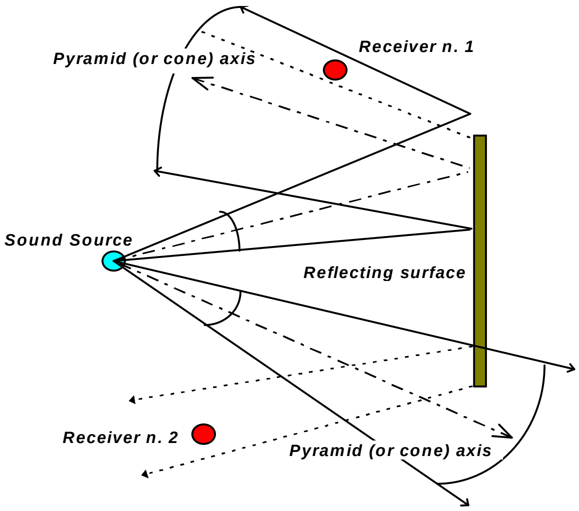
FROM BEAM TRACING TO PYRAMID TRACING

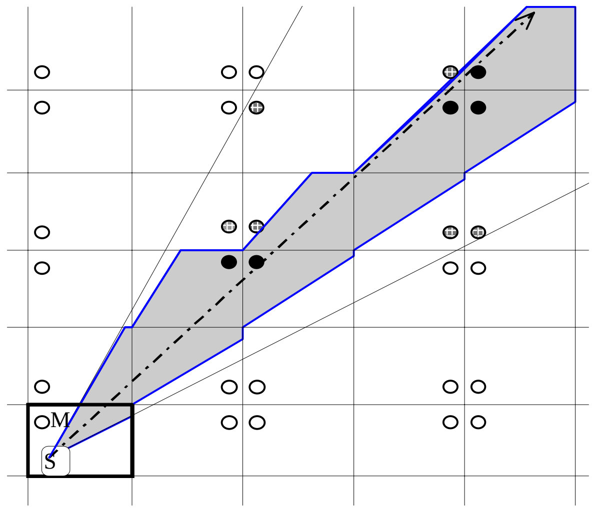
When the first diverging beam tracing programs appeared, it was soon clear that their speed (compared to the original Ray Tracing) was counterpoised to the birth of two previously unknown problems: the multiple detection of the same path and the underestimation of the reverberant queue. The first problem was typical of the cone tracers: as cones don't cover completely the source "sphere" surface, it was necessary to overlap adjacent cones, and an algorithm is required to avoid multiple detections or to "weight" the energy so that (on average) the multiple contributions produce the correct sound level. Some famous conical beam tracers are known [3,4], implementing different techniques to correct this point. However, it is obvious that the Pyramid Beams don't suffer of this problems, as adjacent pyramids cover perfectly the source "sphere", as shown in this picture:



The subdivision of the surface in triangles is made using a modified version of the original one proposed by Tenenbaum et al. [5], proceeding by subsequent subdivisions of the 8 "octants" of the sphere: this way the number of pyramids generated can be any power of 2, and all them have almost the same base area, giving a nearly isotropic sound source.

Obviously the tracing of the three corners follows the reflection history of the pyramid axis, even when one corner actually hits a different surface: this cause the second afore-mentioned problem, as statistically it can be shown that in this way a number of high-order image sources are not correctly detected from the algorithm (although some other “false” ones are detected). This can be shown from the following two pictures:





Looking at the left-side picture, one can see that receiver 1 is being detected inside the beam, while it should not, but receiver 2 is completely missed, while it should receive the reflected wave. Often the beam tracing is used to “discover” valid image sources: if they are checked for “visibility” (as usual in image sources program) a large number of them are discarded, as shown in the right part of the picture. However, also leaving them as valid to “compensate” for the missing ones does not completely remove this systematic effect: in fact the number of valid detections is **always** underestimated, as clearly discussed by Maercke&Martin [3] and Naylor [4].

The following discussion applies strictly only to Sabinian sound field: an original extension to non-Sabinian fields is reported in the next paragraph.

The number of wavefronts impinging in the time unit on a point receiver increases with the square of the time elapsed from the sound emission, following an expression of the type:

$$n(\tau) = \frac{4 \cdot \pi \cdot c^3 \cdot \tau^2}{V} \qquad (1)$$

However, the number of detections produced with a diverging beam tracer follows eq. (1) only while the aperture of the beams is smaller than the size of room surfaces; when the base of the beam is larger than the room, all the receivers are hit at each reflection of the wavefront, so that the number of detection per second tends to a constant value:

$$n(\tau \to \infty) = \frac{c \cdot N}{l_{mfp}} \qquad (2)$$

in which l_{mfp} is the mean free path length, and N is the total number of beams traced.

At this point we introduce the definition of the Critical Time t_c: it is the time at which the theoretical parabola of eq. (1) intersects the constant value of eq. (2).

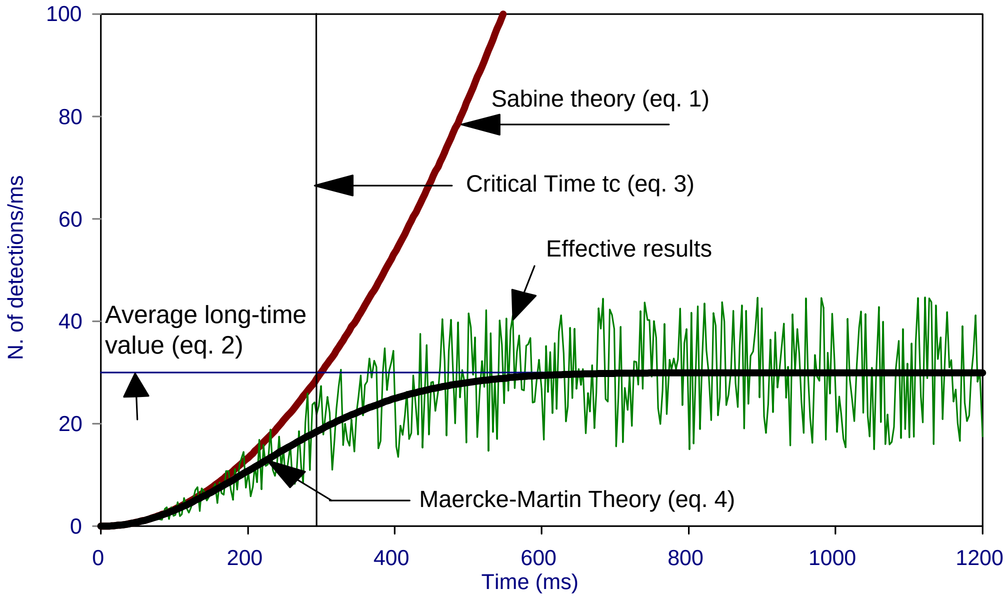
With some modifications of the expression reported by Maercke&Martin [3], the value of the critical time can be computed as:

$$t_c = \frac{l_{mfp}}{c} \cdot \sqrt{\frac{N}{4 \cdot \beta}} \qquad (3)$$

Where the numeric parameter β depends on the “width” of the beams, and its value is 0.3 for triangular beams (pyramids). The effective “smoothed” detection rate can be expressed as:

$$n(\tau) = \frac{4 \cdot \pi \cdot c^3 \cdot \tau^2}{V} \cdot \left(1 - e^{-\frac{t_c^2}{\tau^2}} \right) \tag{4}$$

The following picture shows the effective results of an actual case with Ramsete:



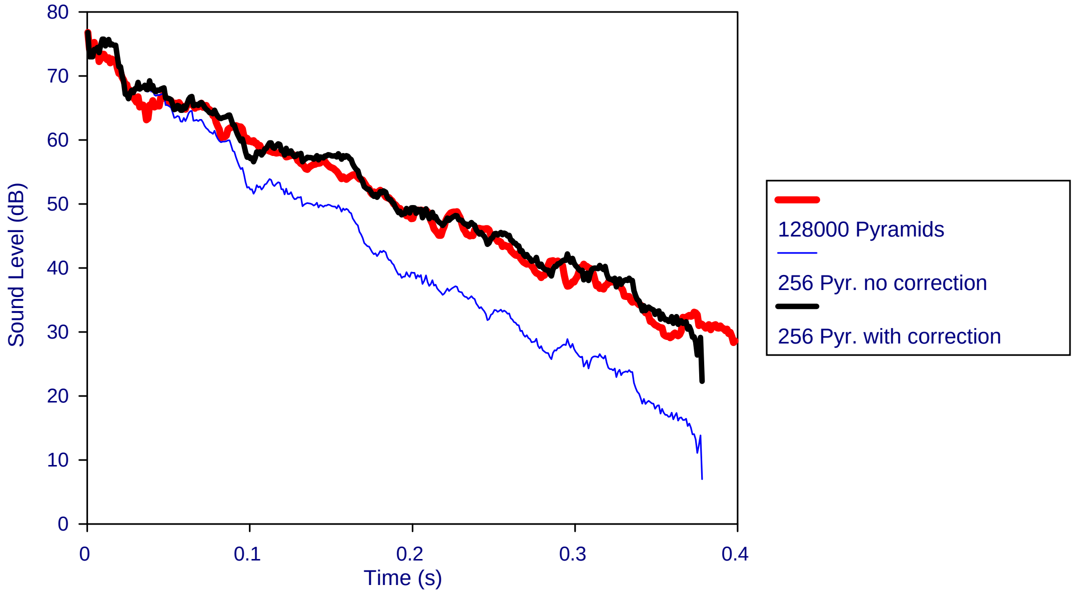
Various authors tried to correct their beam tracers based on the previous formulas: Maercke and Martin employed an additive correction, superimposing an additional statistic queue to the impulse response computed from the conical beam tracing, while Naylor proposed to multiply the underestimated queue for a time-varying correction factor, obtained as the ratio of eq. (1) and (2). In Ramsete a further improvement is made, as the multiplicative correction factor employed is the ratio of eq. (1) and (4), so that no sudden jump in the detection density is present.

Furthermore, the correction is separately computed for each receiver, avoiding the concept of “diffuse” sound field, based on the statistics (mean free path) of that particular receiver. In this way the program can be used also in cases where the receivers are placed in different acoustic situations (coupled rooms, indoor and outdoor, etc.), and the reverberant queue can show double slopes and late echoes. For these reasons, Ramsete cannot be consider an “hybrid” room acoustical model: no distinction is made between “early” deterministic part of the Impulse Response and “late” statistical part, although for times larger than the critical one the behaviour of the acoustic field is estimated only from just a fraction of the “true” total number of arrivals.

On the other hand, Ramsete can work also as a purely deterministic model: if the number of pyramids is high enough, the critical time becomes larger than the Impulse Response length, and in practice no correction is applied, making it possible to obtain “exact” values of the more sensitive acoustic parameters. However, in practical cases a very little number of pyramids is needed to obtain reasonably accurate estimates of the Sound Level and of the Reverberation Time (that are all what is required for noise control calculations), providing that the time resolution selected for the Impulse Response is not too small.

For these reasons Ramsete is incredibly fast in computing Sound Level Maps in complex geometries: only in rare cases a 20 minutes computation is required, and usually all the work is made in a couple of minutes for each sound source (on a 66 MHz 486).

The following graph compares the results obtained with a very accurate calculation (128.000 pyramids) with those obtained with a fast one (256 pyramids): the latter is presented both without and with queue correction, and it is shown that the decay becomes nearly the same as with the large number of rays.



Another pyramid tracing program was independently developed by Lewers [6], but it is based on quite different assumptions: in fact Lewers tried to correct the reverberant queue underestimation superposing a diffuse radiant exchange model, as he was thinking that the lack of diffusion was the cause of the underestimate, while it is inherent in any diverging beam tracing.

EXTENSION TO NON-SABINIAN SOUND FIELDS

From the previous chapter it is clear that Ramsete can be used to study also non Sabinian sound fields, but in these cases the previous theory is not valid: one should employ a very large number of pyramids to ensure that no queue correction is needed, and this is unacceptable, as industrial factories are usually highly non-Sabinian. In fact, the absorption distribution is non uniform, the dimensions of the room are strongly different, and the reflections paths assume values very dispersed around the mean free path, due to the presence of a lot of obstacles.

Principally two effects can be noted if one try to employ an evaluation scheme of the queue correction similar to the previous one:

- The “true” number of reflections per unit time does not increase with time raised to the power of 2, but with a lower exponent α
- The Critical Time is usually lower than the one computed with eq. 3

However, if the correct value of the critical time is estimated (properly adjusting the value of β), and if the correct exponent α is employed in the queue correction factor, the program still produces sufficiently accurate impulse response estimates also with a very little number of pyramids. The correct couple of α and β can be found imposing the coincidence (in the least squares sense) of two decays, one computed with a (very) large number of pyramids, and the second one with just 256. As the tracer does not apply the queue correction (this is done inside the post-processing code), it is not needed to make the calculations many times. After obtaining the right values, one can study various acoustic treatments and sound source scenarios without the need to change α and β, as they depends only on the macroscopic geometry of the problem.

In the last year the author employed Ramsete for the study of a large number of practical cases: theatres, small rooms, factories, tunnels, outdoor propagation. In each case an accurate evaluation of the optimal values of α and β was conducted based also on experimental measurements, and the following guidelines can be assessed:

- When the three dimensions of the space are comparable, and there are no obstacles, the “Sabinian” values (α=2, β=0.3) are usually correct, independently from other factors
- If there are obstacles in otherwise Sabinian rooms, α remains 2 while β is decreased towards 0 (typically 0.1).
- In “very low rooms” usually values of α=1.6 and β=0.4 are satisfactory
- Outdoors β=0 (in this case α doesn’t matter!)
- In tunnels α ranges from 1 to 1.4, and β from 0.1 to .5

Obviously, when the number of users of Ramsete will increase, and a greater data quantity shall be available, these values shall become more accurately defined.

CONCLUSIONS

In the study of the noise propagation inside (and outside) factories, the employment of an “accurate” Ray Tracing program is impractical, due to the large computation time required; on the other hand, diverging beam tracers developed for Sabinian sound fields produce systematic errors, that can be minimised only increasing the number of beams.

Due to its original pyramid tracing implementation, Ramsete can be used to produce very fast evaluations of the sound propagation, including shielding effects and wall transmission, even in highly non Sabinian environments (and also outdoors!), provided that the queue-correction parameters α and β are properly adjusted for the geometry under study.

Once the theory exposed in this paper has been properly understood, the program can be easily used also from non skilled technicians, due to its intuitive Windows interface, its interactive graphical pre and post processors, and the capability to **listen** through earphones in a few minutes the results of each simulation.

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