VERIFICATION OF THE ACCURACY OF THE PYRAMID TRACING ALGORITHM BY COMPARISON WITH EXPERIMENTAL MEASUREMENTS OF OBJECTIVE ACOUSTIC PARAMETERS

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ABSTRACT

The paper summarise the results of a large verification experiment, in which the numerical previsions obtained through a new Pyramid Tracing program are compared with experimental results coming from very different geometric cases.

Firstly the Pyramid Tracing implementation made in the RAMSETE program is briefly explained, together with the particular assumptions made on the sound source directivity and on the acoustic behaviour of the surfaces.

Then some experimental cases are introduced: for each of them, a numerical simulation of a simplified geometry is conducted, and the numerical results are compared with the experimental ones in terms of standard objective acoustic parameters (computed accordingly to ISO/DIS 3382). The discrepancies are stressed out, and the sensitivity of the numerical results with the variation of the computational parameters is discussed.

THE PYRAMID TRACING IMPLEMENTATION IN RAMSETE

Pyramid Tracing is a new numerical modelling technique, suited to room acoustics and outdoor calculations [1,2,3,4]. The first known approach to Pyramid Tracing was made by Lewers [5], but in that case it was used in conjunction with a radiant exchange model. The main advantage of Pyramid Tracing over other diverging beam tracers (cone tracing [6], circular gaussian beam tracing [7]) is the fact that pyramids perfectly cover the surface of a spherical source, while cones cause overlapping or uncovered zones, as shown in fig. 1. This avoids the need of a multiple detection check, speeding up the calculation.

As with any other diverging beam tracer, there is an unavoidable progressive under-estimate of the late part of the impulse response, due to the increase of the base of the pyramid, that becomes larger than the room: the model does not take into account the leaking energy associated to the outbounding area. In usual cone or beam tracing programs this fact is corrected adding a statistical tail to the first part of the impulse response: this way the model become hybrid [6,7]: early reflections are found in a deterministic way, late reverberating tail with a statistical approach.

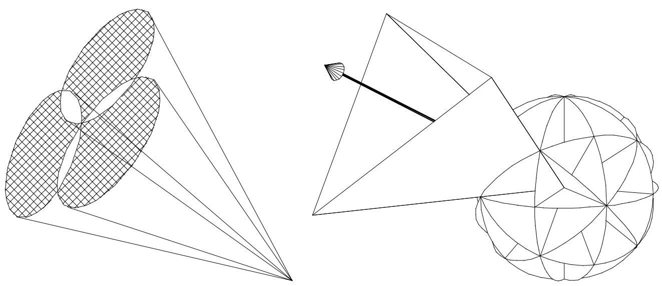

Fig. 1 - Comparison between Cone Tracing and Pyramid Tracing

Ramsete does not employ a reverberant tail superposed to the response computed by Pyramid Tracing: the whole impulse response (many seconds) can be computed following the pyramids, and correcting the response of each receiver multiplying it by a time-varying correction factor, computed accordingly to a modified theory originally developed by Naylor [6] and Maercke-Martin [7]. This requires proper adjusting of two adimensional parameters (α and β) [4]: when this is done, fast and yet accurate computations can be done with a very little number of pyramids (typically 256 - 1024).

Besides the particularities of the pyramid tracer, it must also be noted that the program comes with an innovative Source Manager [8]: it manages the source directivities and sound power data files, and make it possible to automatically define directivity balloons (with standard 10° by 10° resolution) from experimental measurements conducted according to ISO codes 3744 and 3746, with direct reading of the most common R.T. Analysers file formats. This is particularly important for the noise sources, for which no directivity data are usually collected.

However the program easily imports also the loudspeaker directivity data stored in the Bose Modeler (TM) and EASE (TM) format.

Another point that need to be explained here is the capability to treat “holed” and “obstructing” surfaces, as this greatly speeds up the program. Usual surfaces are quadrilateral plane faces, defined by the coordinates of their vertexes. If they are declared “obstructing”, additional tests are made to find the sound attenuation of pyramids “passing through” the panel and being diffracted from its free edges (automatically located). On a surface it is also possible to “attach” three types of entities: doors, windows and holes. Doors and windows are rectangular areas, having absorption coefficients and sound reduction indexes different from that of the wall. The holes are closed polylines, that define regions where the pyramids can freely pass through an obstructing wall.

These features produce a noticeable reduction in computing time, as the number of (main) surfaces is reduced, and the complete set of tests is conducted on the “obstructing” surfaces only.

Ramsete’s accuracy was already checked by comparison with a “reference” Ray Tracing program [4]. Nevertheless, the question if the simulations are sufficiently realistic is still open, as both Ray Tracing and Pyramid Tracing rely on the same basic geometrical acoustics assumptions.

For these reasons comparison with experimental data need to be made. A first one, regarding outdoor propagation, was already published [3]. In the following, the results of three comparisons conducted in closed spaces are reported: in the first case the numerical simulation was finished before the experimental measurements were made, while in the other two they were available during the setup of the numerical model.

A LECTURE ROOM AT THE PTB (PART OF A ROUND ROBIN PROGRAMME)

Michael Vorlander (PTB, Braunschweig) organised in 1994 a large Round Robin on room acoustic computer simulations [9]. The participants were asked first to model a room actually existing at PTB, basing just on schematic drawings and photographs: each participant was left free of using proper geometrical simplifications and absorption coefficient data. Then some participants were allowed to take experimental measurements in the room, using the preferred techniques. After this, a second simulation was conducted, employing absorption data unified for all participants.

Here just the numerical and experimental results obtained by the author are reported: for comparison with the other data, please refer to Vorlander’s paper [9].

Picture 2 shows a perspective view of the lecture room, as modelled with Ramsete CAD, and the 1 kHz reverberation time for various source-receiver pairs. The two omnidirectional source positions and five receiver locations are clearly shown. In each receiver and for each source position 8 acoustic parameters had to be computed (and measured) according to ISO/DIS 3382: T30, EDT, D, C, Ts, G, LF, LFC. Actually Ramsete can compute all of them, but at the time of the first test the latter two parameters were not included.

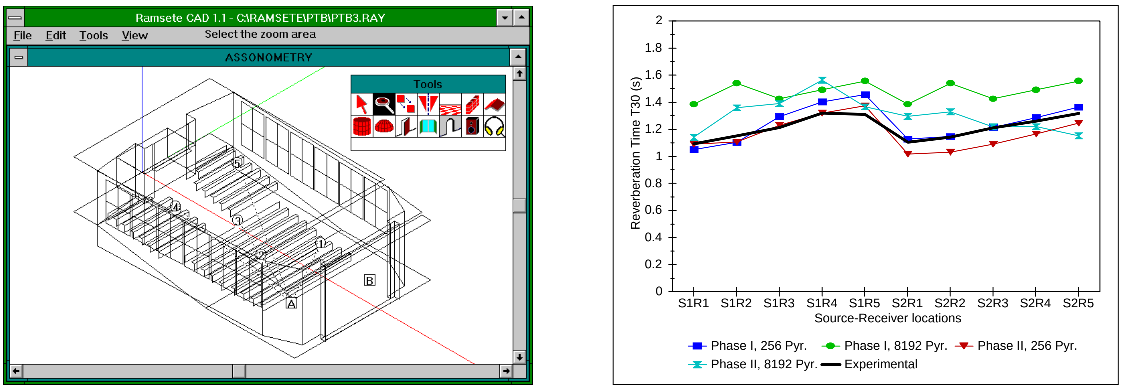

Fig. 2 - Geometry of the lecture room (left) and reverberation time T30 (right)

For these simulations, two very different numbers of pyramids were used: 256 and 8192. This was done to test the “convergence” of Pyramid Tracing to right values increasing the number of pyramids.

The experimental data were collected with a measuring system partly provided by the author (portable PC fitted with a MLSSA board, omnidirectional 1/2” microphone), partly kindly provided by PTB (power amplifier, Norsonic dodecahedron). Two 64-k points MLS Impulse Response measurements were made in each position, moving the microphone 30 mm apart. This enabled the measurements of Lateral Fractions (LF, LFC) without employing a pressure gradient microphone, or a sound intensity dual microphone probe [10].

For each source/microphone pair the difference between computed and measured parameters was calculated in the octave band of 1 kHz. An RMS average was taken of these 10 data, giving this way greater weight to largest differences. The following table shows the RMS averages concerning the 4 cases studied: with personal or unified absorption data and with 256 or 8192 pyramids; the computation times (for both sources) are also shown:

	T30 (s)	EDT (s)	D (%)	C (dB)	Ts (ms)	G (dB)	LF (%)	time (s)
Phase I - 256 pyramids	0.06	0.31	18	3.52	24.1	2.97	4.9	172
Phase I - 8192 pyramids	0.28	0.36	20	4.10	26.1	2.91	/	6046
Phase II - 256 pyramids	0.07	0.31	14	3.15	19.6	1.11	4.0	174
Phase II - 8192 pyramids	0.16	0.15	11	2.09	11.6	1.35	6.0	6150
Subjective limen	0.07	0.05	5	0.5	10	1	5	////

The last row is the subjective limen for discriminating substantial parameter differences, as suggested by Vorlander. It is evident that in the first phase some errors were made in choosing the absorption coefficients, while in the second phase more accurate results were obtained. Although increasing the number of pyramids a certain improvement is obtained (not for all parameters, however), it is clear from these results that Ramsete's deviations are usually over the subjective limens.

It can be concluded that there is no matter in increasing the computation time with large numbers of pyramids, as with 256 the accuracy is only slightly reduced. The Pyramid Tracing does not pretend to be the more accurate simulation program, but launching 256 pyramids it is indubitably very fast! Looking at fig. 1, it can be seen that actually the T30 estimates obtained with 256 pyramids are better than those obtained with 8192.

A CHURCH RESTORED AS AUDITORIUM AND CONCERT HALL

The Basilica of S.Domenico in Foligno is a large, old church, no more used for religious ceremonies: after many years in which it was left unused, it has been now restored and adapted as a general purpose room. Actually it has been used as an auditorium for large conferences, but it will be used soon also as a concert hall.

Experimental measurements were conducted inside the room with a non-omnidirectional loudspeaker (Davoli AA503), a MLS acquisition board (MLSSA A2D160) and a binaural dummy head (Sennheiser MKE 2002) in 24 points uniformly distributed in the main floor and in the apse. The same configuration was also reconstructed with Ramsete, using approximate directivity and power data obtained through ISO 3744 measurements previously conducted [8]. 2048 pyramids were used for this comparison, with a computation time of 24' 30".

The graphs in fig. 3 show the reverberation times and the contour maps of RASTI.

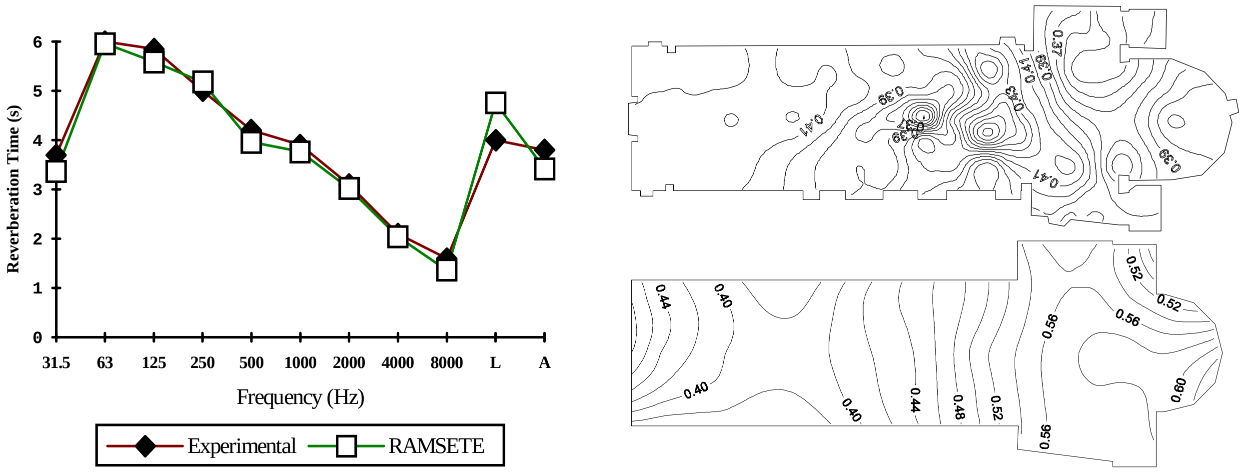

Fig. 3 - Reverberation Times (left) and RASTI (right): the upper map is experimental, the lower numerical.

It can be shown that the reverberation times are almost the same. The RASTI maps look quite different, as the experimental one exhibits complex patterns that are missing in the numerical one. But the numerical values in the single points are not very different: the RMS averaged difference between numerical and experimental RASTI values is 0.114, that is of the same magnitude as the experimental error in RASTI measurements. Obviously a better accordance could have been obtained if more detailed directivity data were available for the speaker used.

A LARGE SPORT ARENA

The Sport Arena in Modena is a large building, with an internal volume of 70000 m^3, and is capable of more than 5000 seats on the tiers. In case of rock concerts, other 1000 seats are located in the parterre. This hall has a very bad acoustics reputation, due to large reverberation times, echoes and focalisations.

Experimental measurements were conducted in 44 points using a blank shot pistol, an omnidirectional condenser microphone and a DAT recorder. The impulse responses were then transferred to a PC through a low cost 16 bit audio board, converted in MLSSA .TIM format and then analysed as they were obtained from MLS measurements.

The numerical model of the sport arena was made by AutoCAD, and imported in Ramsete, resulting in more than 1800 surfaces of 14 different materials. 256 pyramids were used for calculation, giving a computation time of 130 s. Here only the Center Time results are presented as graphical maps for the 1 kHz octave band.

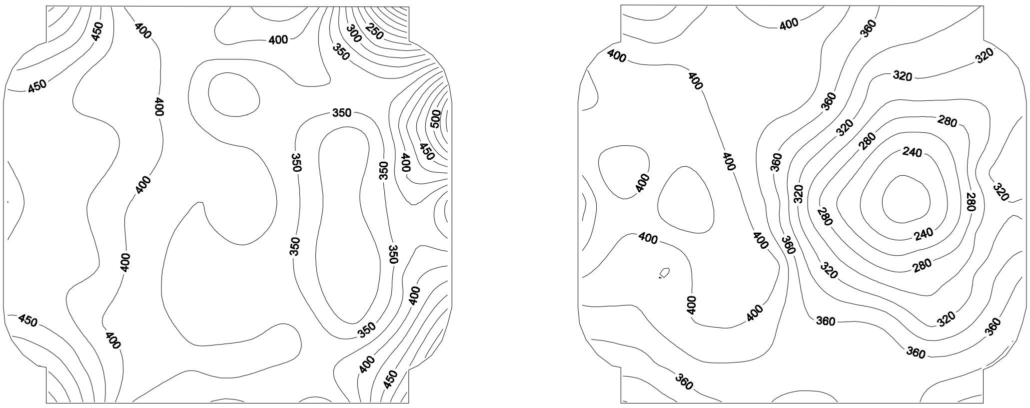

Fig. 4 - Center Time in Modena’s Sport Arena - Experimental (left) and Numerical (right)

The values are similar in points located far from the source, but the experimental values obtained near the source are higher than the numerical ones (which seem more reasonable). Probably these measurements are affected by overload in some of the analog links, causing an underestimate of the direct wave in comparison with the reverberant tail. This problem is present only for points very near to the impulsive source. The RMS averaged difference between numerical and experimental values is 51.2 ms, while discarding the 6 points around the source it reduces to 43.8 ms.

CONCLUSIONS

The comparison with experimental results shows that the numerical previsions obtained by using the Ramsete program are affected by errors, that can be explained only partially with discrepancies between the data inputted to the model and the reality. Certainly some approximations intrinsic to the actual Pyramid Tracing scheme make it impossible to get very accurate results: this means that the program need to be extended incorporating diffusion and scattering effects, respectively caused by rough and limited size surfaces.

Anyway the program is very fast and accurate enough for comparative evaluations, or for simulations in industrial workplaces, where only the overall SPL values are required. In many cases the intrinsic errors of the pyramid tracing are lower than those associated with limitations present in other “more accurate” computation schemes, as those regarding the source directivity, the diffraction from obstructing panels and the sound energy passing through low-insulating partitions.

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