Just4RIR
User manual

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Introduction

Just4RIR is an autonomous tool performing room acoustic computations. The technology uses a fast algorithm to propagate acoustic rays within the room and generate image-sources. The main features are :

- Generation of the multi-band echogram (Room Impulse Response).
- Transformation of a mono-audio file to reverberated one.
- Vizualization of acoustic rays or image-sources.

Inputs are .obj file containing the mesh and/or source and listener objects. They can be generated on Blender and transmitted to Just4RIR easily with an optional add-on. Thus, visual results in the acoustic domain can be obtained easily from Blender with a few clicks.

1 How to install

To to github and download the version corresponding to your OS.

2 How to use Blender add-on

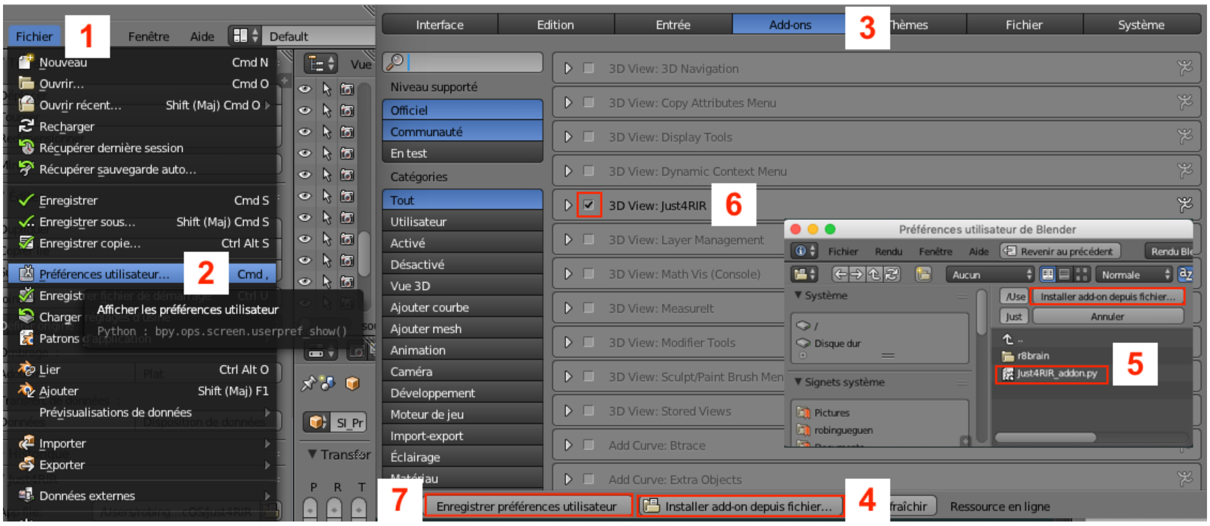


FIGURE 1 – Installation of the Blender add-on.

This option is recommended but not necessary to use Just4RIR room acoustic software. First, install the add-on on your blender interface (see fig.1). In Blender, go to *File/User preferences/Add-on*. Click on "*Install add-on from a file*" and select *Just4RIR_addon.py*. Don't forget to enable the add-on **3Dview :Just4RIR** and to save your preference.

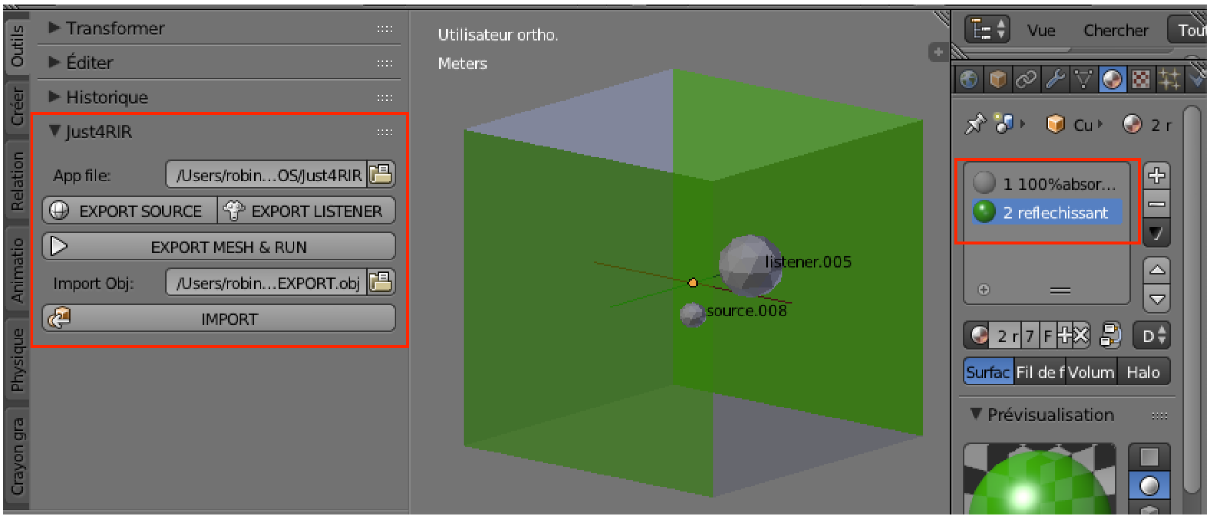


FIGURE 2 – Add-on Just4RIR for Blender.

Just4RIR tool is located in the Tools tab on the left panel. In the first field the user must select the file Just4RIR.exe [1]. Buttons EXPORT SOURCE and EXPORT LISTENER allow to export respectively source and listener separately. EXPORT MESH & RUN button export all objects selected including sources and listeners and launch Just4RIR program. In the field import Obj has to be loaded mesh4RIR_EXPORT.obj located in the same folder as the file Just4RIR.exe. Clicking the IMPORT button will import this file. To be read as a source, an object has to contain the word "source" in its name. To be read as a listener, an object has to contain the word "listener" in its name. Material are assigned to faces of the mesh using Blender material interface. The

1. For macOS users, this file is in /Just4RIR.app/Contents/MacOS folder.

default material is 50% absorbant, if the user wants to change this property, a reference number written at the beginning of the name of the material followed by a space. All materials can be found in the file Material.txt located in the folder of the file Just4RIR.exe and can be modified (see section 3.2).

3 How it works

3.1 Reading mesh

Just4RIR software reads an .obj mesh file at start-up. Three options are available :

- Just4RIR is launched from Blender (see section 2). (**Recommended**).
- The user indicates where is the .obj mesh (filepath asked at start-up).
- The mesh file is named "mesh4RIR.obj" and is located in the same folder than Just4RIR.exe file[1]. This file is automatically read.

The .obj file must contain triangular mesh of the room with normals oriented to inside.

The sources and the listeners can be some objects in this file. To be treated as such, the name of the mesh object has to contain respectively the word "source" and "listener". Just4RIR use the center of the objects to determine their position. Listeners also have a radius which is the distance between the center and the furthest element of the object. **The smallest the radius of the listener is, the most precise is the mesure, but, the length of the echogram will be shorter (eq 12).** If no object "source" or "listener" are present in the mesh file, a default source and listener will be created at [0,0,0], with a 1m radius for the listener.

3.2 Modifying a material

All materials can be found in the file Material.txt located in the folder of the file Just4RIR.exe. This file is the Odeon's software [11] material database and can be modified. We advice the user to use a material from this list without any modification. But, this file can be modify for adding new materials if needed. A valid material has to be written on two line :

- First line : "the reference number" [tabulation] "the name of the material".
- Second line : [tabulation] "absorption coefficient for 62.5Hz" [tabulation] "absorption coefficient for 125Hz" [tabulation] ...

The second line need 8 values corresponding to the absorption coefficients from 62.5Hz to 8kHz (octave bands). If you doubt on how to add a new material, just copy one of the existing on and replace the numerical value without modifying the indentation.

To respect the indentation is crucial.

3.3 Configuration

The user interface includes four sections. The top one, named "configuration", contains three tabs :

- **Import** : Allows to visualize sources and listeners informations and to load new one if necessary (see fig.3). The new objects are loaded respectively from files "src4RIR.obj" and "listener4RIR.obj". These mesh files have to be located in the same folder than the Just4RIR.exe file[1].
- **Atmosphere** : Allows to configure air temperature and relative pressure according to norme ISO-9613-1 [1]. A plot allows to visualized the coefficient $\beta(f)$ from 62,5Hz to 8kHz (eq 17) according to the parameters (see fig.4). The acceptable range is described in table 1.

2. For macOS version please note this folder is named MacOS and is situated inside the Just4RIR.app file (Just4RIR.app/Contents/MacOS/).

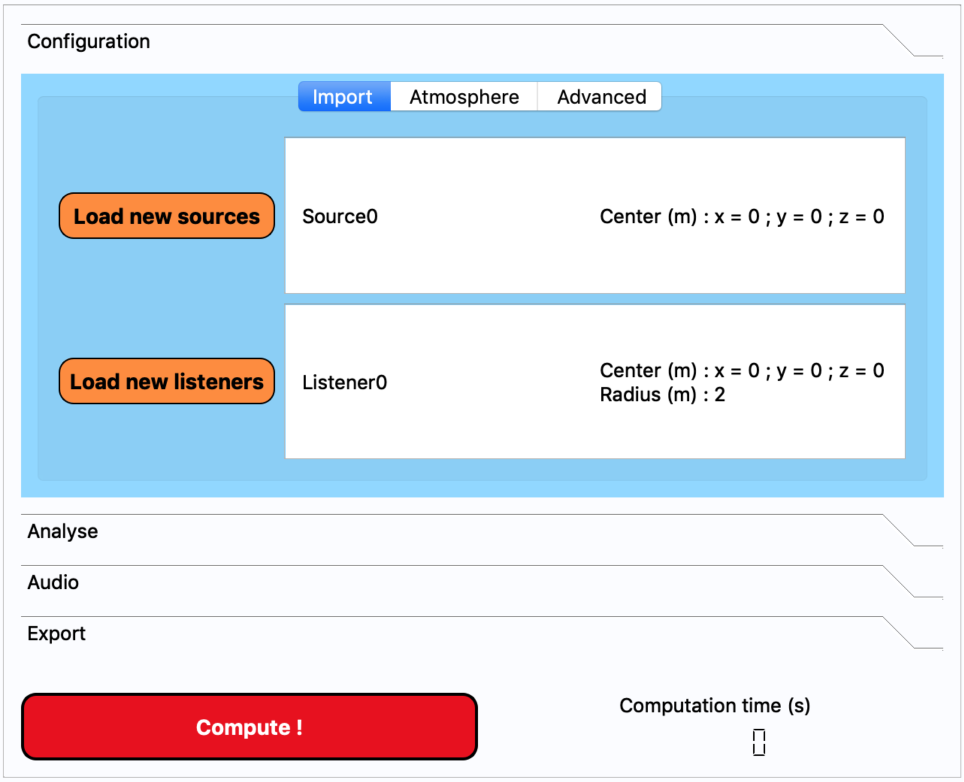


FIGURE 3 – Full user interface open on the section configuration, tab Import.

Parameter	Min	Max
Temperature (°C)	-20	50
Relative Humidity (%)	0	100

TABLE 1 – Atmospheric parameters range.

- **Advanced** : Allows to configure parameters for the computation (see fig.5). On the left side, the user will be able to configure rays distribution. Rays can be directed uniformly (using Fibonacci repartition) and the user can choose the number of rays to emit. For custom use, the "Source vertex" option can be choose to propagate rays according to the source object. In that case rays are still emitted from the center of the object but the direction is determined by each vertex of the object. For example, if the source is a ring refined with 1000 elements, 1000 rays will be emitted from the center of the ring and will propagate on the plan. On the right side, user can choose to stop the computation according to the energy loss (typically 60dB) or to a fixed number of iteration (ie rebound of rays on the walls). For the first option, user can also set a statistical threshold which will determine the precision of the measure (see n factor in section 5.1.2). The minimum and default value is 1. The Impulse response duration is then determine according to eq 12.

3.4 Analyse

Once parameters are all correct for your test, user can click on the red "Comupte !" button (see fig.3). This one propagates rays and create image-sources. On the section Analyse, the user can :

- Display the echogram with or without decay curves (see section 5.3) and according to a sampling frequency or and a gain (see fig.6a and fig.6b).

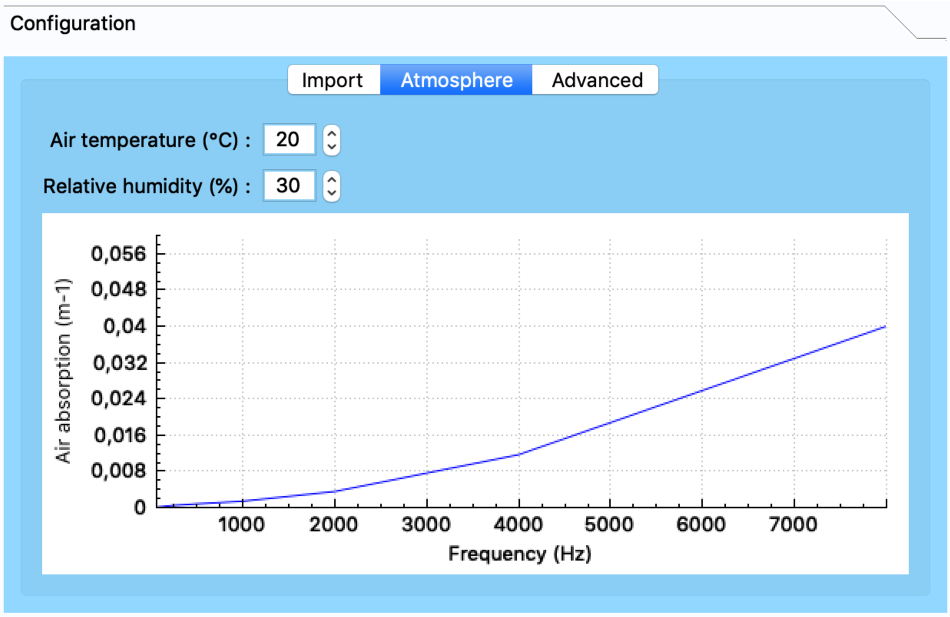


FIGURE 4 – User interface open on the section configuration, tab atmosphere.

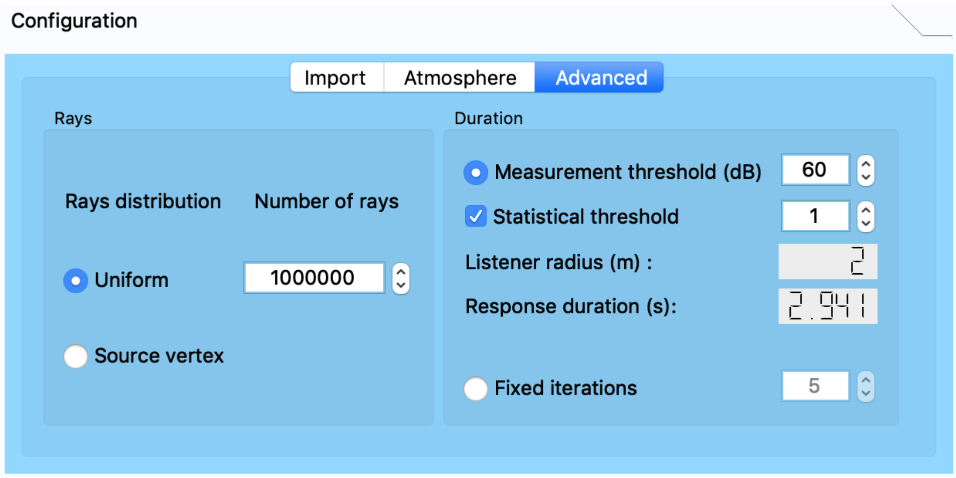


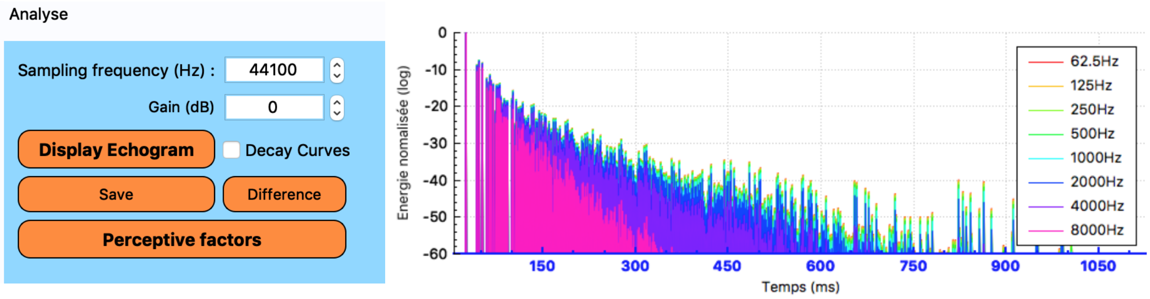
FIGURE 5 – User interface open on the section configuration, tab Advanced.

- Save data of the current echogram. These data are recorded in a .txt file in the same folder as Just4RIR.exe file.
- Display the difference sample per sample between the current echogram and the echogram saved. Please note the sampling frequency has to be the same.
- Display perceptive factors (see section 5.3). These data are recorded in a .txt file in the same folder as Just4RIR.exe file.

3.5 Audio

On the section Audio, the user can reverberated a mono-wav file according to the room acoustic computation.

The audio must be a mono .wav file.



(a) Full user interface open on the section analyse.

(b) Exemple of echogram.

FIGURE 6 – User interface open on the section analyse.

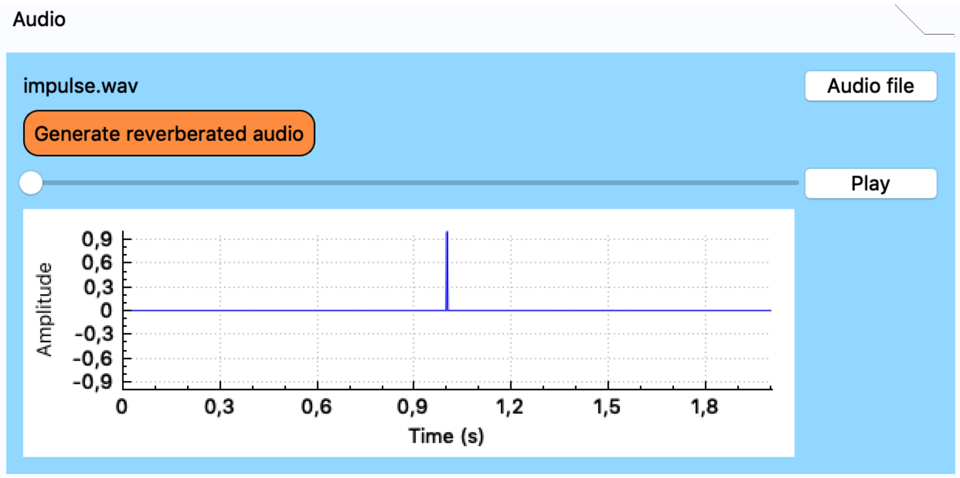


FIGURE 7 – User interface open on the section audio.

Before clicking on "Generate reverberate audio" the displayed signal is the original audio file. At the end of the process, the signal is reverberated. By clicking play the user can listen the displayed signal. The convolution result (ie reverberated signal) is recorded has a .wav file in the same folder as Just4RIR.exe file.

3.6 Export

The section export allows to generate new .obj files to observe results of computation. These .obj files are recorded in the same folder as Just4RIR.exe file with the name mesh4RIR_EXPORT.obj. They can easily be imported in Blender for visualization.

3.6.1 Image-sources

The "Image-sources" button (see fig.8) export an object composed of square faces at the position of each image-sources[3]. These square have a normal oriented to the listener and a material named as the image-source energy. The color represents the range covered by the signal, red is the direct sound and blue is the attenuation threshold. If the "Projected" option is checked, the image-sources will be displayed on the walls of the room allowing the user to see where the sound comes from (last echo). If this option is not selected, image-sources are in their real location. The "Merge" option permits to reduce the number of image-sources by merging

3. If this object is imported to Blender with the Just4RIR add-on, the squares will be transformed into spheres.

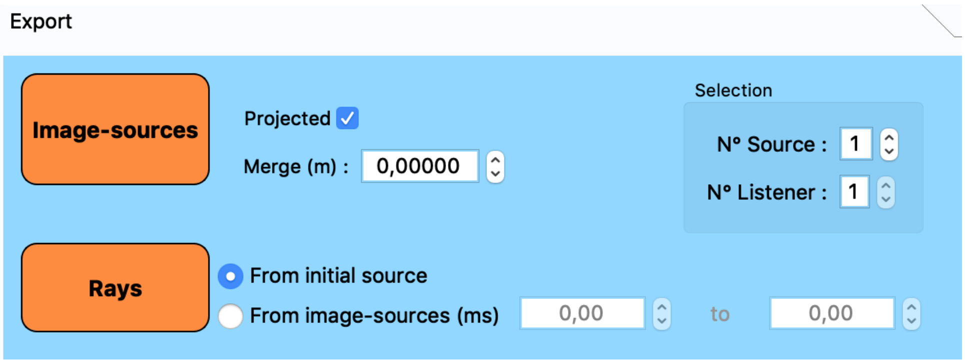


FIGURE 8 – User interface open on the section export.

those close to each other. In case of multiple sources or listeners, the user can select which one the display is about. To display the results for all sources, please indicated N°Source : 0.

3.6.2 Rays

The Rays button export mesh line to visualize the path of the acoustic rays has it is compute. With the "From initiale source" option, the user need to be in "fixed iterations mode" (see fig.5) to avoid huge files. Once the computation done, the second option "From image-sources" can be used. This one allows to display one ray per image-sources corresponding to a certain range in the echogram.

4 How to go in the code

This section describes briefly the function of the code and their aim.

- analytique.cpp : (not used) Development code for shoes box analytic case.
- audio.cpp : Functions for audio reading, writing and convolution.
- data.cpp : Perceptive factors management.
- fftext.cpp, fftlib.cpp and matlib.cpp : Generic function used for performing FFTs.
- fonction.cpp : Mathematical functions created for the project and object declaration like CoordVector (vector of coordinates).
- mainwindow.cpp : The user interface configuration and initial loading.
- objreader.cpp : Read obj files and load the room mesh, sources and listeners.
- objwriter.cpp : Creation of .obj files for export section (see fig.8).
- octree.cpp : Function for tree-based acceleration process (use if the number of vertex is high).
- physic.cpp : Atmosphere and materials management.
- plotwindow.cpp : Echogram plot management.
- qcustomplot.cpp : open source function to create plots.
- raytracing.cpp : rays propagation management.
- reglin.cpp : generic function for linear regression.
- rir.cpp : image-sources and echogram management.

The add-on Blender is modifiable by deleting the add-on Just4RIR in the user preferences on the File menu, modifying the file Just4RIR_addon.py and install it again (see fig.2)

5 How to understand physics behind

More information about this part in : https ://arxiv.org/abs/1811.05784.

5.1 Acoustical energy modelization

5.1.1 Continuous domain equation

By modelling a point sound source located at 0 as a localized pulse in space, the associated acoustical energy E(t) propagates [6] over time on a spherical surface $S(t)$ centered in 0, as :

$$E(t) = E_0 \int_{S(t)} \overrightarrow{I}(t) \cdot \overrightarrow{ds} \qquad \forall t > 0, \tag{1}$$

with E_0 the initial energy and $\overrightarrow{I}(t)$ the acoustical intensity. According to the first principle of thermodynamics and by neglecting the effects of losses related to the absorption of the propagation medium, the acoustic energy is preserved over time and we may normalize the source in such a way that :

$$\int_{S(t)} \overrightarrow{I}(t) \cdot \overrightarrow{ds} = 1 \qquad \forall t > 0. \tag{2}$$

The propagation being isotropic, we deduce that :

$$||\overrightarrow{I}(t)|| = \frac{1}{4\pi d(t)^2} \qquad \forall t > 0, \tag{3}$$

reflecting that intensity decreases as the square of the distance to the source $d(t)$. The energy carried by a solid angle Ω_σ is obtained by integrating on the portion $\sigma(t)$ of $S(t)$ and satisfies :

$$E_\sigma(t) = E_0 \int_{\sigma(t)} \frac{1}{4\pi d(t)^2} ds = \frac{E_0}{4\pi} \Omega_\sigma. \tag{4}$$

The energy of a solid angle is constant over time and corresponds to a portion of the initial energy E_0. Thus, subdividing $S(t)$ in N portions $\sigma_i(t)$, the total energy can be decomposed as a sum of elementary energies, carried by corresponding solid angles Ω_i, such as :

$$E(t) = \sum_{i=1}^{N} E_i(t) = \frac{E_0}{4\pi} \sum_{i=1}^{N} \Omega_i \qquad \forall t > 0. \tag{5}$$

One can notice that $(\Omega_i)_{i \in [1,N]}$ is a directional basis, representing the energy propagation by piecewise constant elements. Furthermore, for greater clarity, we definitively set in the following $E_0 = 1$.

5.1.2 Discrete model

To numerically represent the energy propagation, we have to discretize basis $(\Omega_i)_{i \in [1,N]}$ in equation 5. For this purpose, we define a ray object composed by :

- Its origin x_i,
- Its direction vector $\overrightarrow{u_i}$,
- The energy that it carries E_i.

For example, with an omnidirectional source [4] considered before, N rays are given by :

- The source coordinate ($x_i = x_s$, $\forall i \in [1, N]$),

4. For a directional source, a non-uniform spatial sampling may be used.

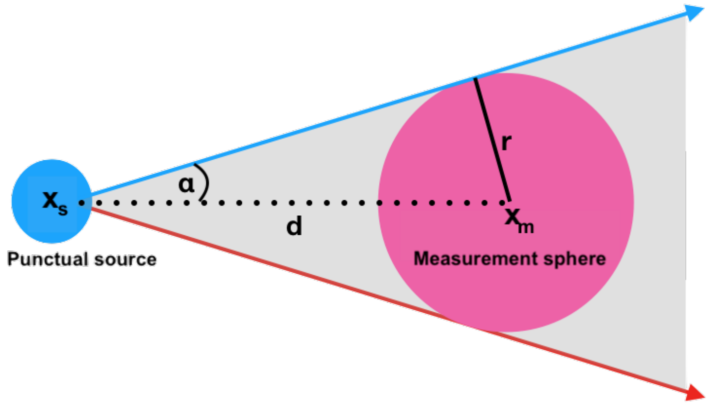


FIGURE 9 – Representation of a r-radius measurement sphere centered in x_m, receiving energy from a sound source in x_s.

- A unit sphere uniform sampling (e.g. icosahedre subdivision, Fibonacci's rule [7], etc.),
- An uniform energy repartition ($E_i = \frac{4\pi}{N}$, $\forall i \in [1, N]$).

To complete this approach, we have to define a discrete measure of energy propagation. To this end, we consider a r-radius measurement sphere $S(x_m, r)$, centered on x_m (fig 9). We can then add the contributions of a n-rays beam that intersect this sphere to calculate the acoustic energy E_m at the point x_m :

$$E_m \approx \frac{1}{4\pi} \sum_{i=1}^{n} E_i. \tag{6}$$

In the particular case of an omnidirectionnal source, we have :

$$E_m \approx \frac{n}{N}, \tag{7}$$

which means that the measured energy E_m is statistically and naturally represented by the ratio between the number of rays forming a beam to the total number of rays. This formula is nothing but the discretization of the continuous model (eq. 4) in which the measured energy is given by :

$$E_m = \frac{1}{4\pi} \Omega_m, \tag{8}$$

where Ω_m is a solid angle at which the measurement sphere is seen from x_s. Using the notation of the figure 9, we have :

$$\Omega_m = 2\pi(1 - \cos\alpha) = 2\pi\left(1 - \sqrt{1 - \frac{r^2}{d^2}}\right). \tag{9}$$

Considering $\frac{r}{d} \ll 1$, we observe that

$$\Omega_m \approx \pi \frac{r^2}{d^2}. \tag{10}$$

which entails

$$E_m \approx \frac{n}{N} \approx \frac{\pi r^2}{4\pi d^2}. \tag{11}$$

To ensure the existence of this last approximation, beam has to be measurable and count at least one ray ($n \geq 1$). This assumption is crucial to ensure the validity of the concept. Thus, fixing a

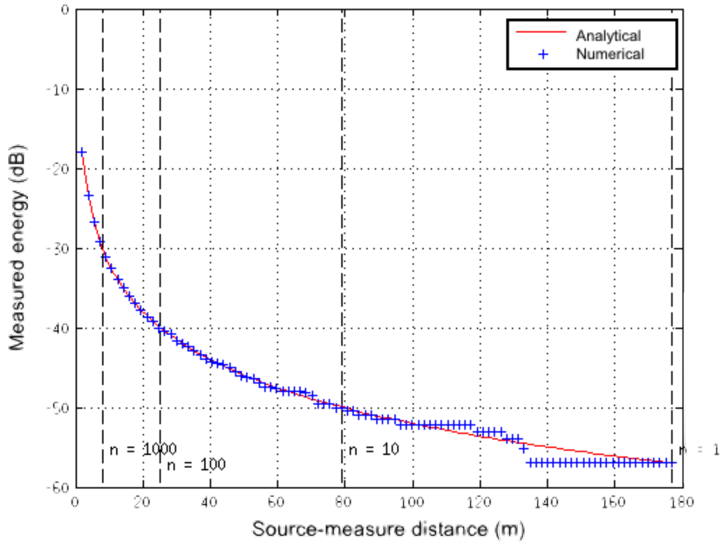


FIGURE 10 – Measured energy (dB) in function of distance between x_s and x_m in meter for $r = 0.36$m and $N = 10^6$. Blue crosses stand for the statistical measure $f(r) = \frac{n(r)}{N}$ and red ligne the analytic function $f(r) = \frac{\pi r^2}{4\pi d^2}$. (computed on *Gypsilab*)

measurement radius r, approximation (11) gives a maximum range of the discrete model :

$$d \leq \frac{r}{2}\sqrt{\frac{N}{n}}. \tag{12}$$

In addition, figure 10 shows how this modelization fills with distance between source and measures. The accuracy of the measurement depends strongly on the number of rays counted, then, the more n increases, the more accurate will be the measurement. Nevertheless, in practice, values for a short distance between the source and the measurement sphere represent direct sound and first reflections, whereas long distances describe the diffuse field. Under this assumption, we can consider this model acceptable for all beam such as $n \geq 1$.

5.1.3 Presence of an obstacle

For the case of acoustic propagation in the presence of an obstacle, we choose to consider only specular reflections (Snell-Descartes laws). Indeed, this approximation is suitable when surfaces are large in comparaison to wavelengths, because diffraction effects can be neglected [6]. For a room, this condition is reached if :

$$ka \gg 1, \tag{13}$$

with k the wave number and a the characteristical diameter of the room [12]. This approach is currently used by room acoustic softwares (e.g. *Odeon* [11], *Grasshopper* [13], etc.) regarding to audible frequency range (62,5 to 15000Hz). In particular, as the theater of Orange has a characteristical diameter of about 50 meters, the high frequency approximation is clearly valid.

Following the discrete model, when an incident ray intersects a flat surface, a reflected ray is generated from the collision point. Noting $\overrightarrow{u_i}$ the direction vector of the incident ray, the reflected direction vector $\overrightarrow{u_r}$ is defined by :

$$\overrightarrow{u_r} = (\overrightarrow{u_i} \cdot \overrightarrow{T})\,\overrightarrow{T} - (\overrightarrow{u_i} \cdot \overrightarrow{n})\,\overrightarrow{n}, \tag{14}$$

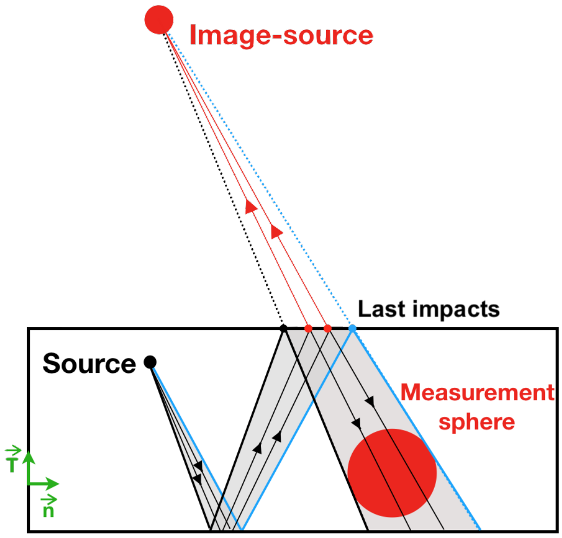


FIGURE 11 – Sketch of the creation of an image-source by successive reflections of a ray on the walls of a room.

Reference	Material name	62,5Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
1	100% absorbent	1	1	1	1	1	1	1	1
2	100% reflecting	0	0	0	0	0	0	0	0
107	Concrete block, coarse [5]	0.36	0.36	0.44	0.31	0.29	0.39	0.25	0.25
3000	Hollow wooden podium [6]	0.4	0.4	0.3	0.2	0.17	0.15	0.1	0.1

TABLE 2 – Examples of absorption coefficients given in the online *Odeon* database [11].

with $\vec{T}$ the tangent basis and $\vec{n}$ the normal vector to the surface. Moreover, the energy of the reflected ray is obtained by :

$$E_r(f) = E_i(f)(1 - \alpha(f)), \tag{15}$$

with $\alpha(f)$ the absorption coefficient of the surface that depends on of the frequency f. Practically, the absorption coefficients are often given per octave bands and can be found in various databases. Both *Gypsilab* and *Just4RIR* use the open access *Odeon* database [11] defined on eight octave bands (see table 2).

Finally, considering wall absorption, energy measured statistically (eq. 11) is extended by :

$$E_m(f) \approx \frac{n}{N}(1 - \alpha(f)), \tag{16}$$

that we generalize to

$$E_m(f) \approx \frac{n}{N}\prod_{j=1}^{m}(1 - \alpha_j(f)), \tag{17}$$

in the case of m reflexions.

5. Harris, 1991
6. Dalenback, CATT

5.1.4 Image-sources

Although the generalized formulation (17) may be sufficient to generate room acoustic data, we also construct images-sources from the path of rays. To this end, when rays intersect the measurement sphere and following the reverse return principle, they are retro-propagated along the last direction vector. Thus, from this measurement sphere, rays focus on punctual images-sources (see fig. 11). Each image-source is then located relatively to the listener and carries an energy according to equation (17). By noting $(x_s)_{s\in[1,N_s]}$ the relative position of the N_s image-sources and $(E_s)_{s\in[1,N_s]}$ the associated energy, couples $(x_s; E_s(f))_{s\in[1,N_s]}$ contain all useful informations for room acoustic analysis and auralization.

First of all, relative distance of each image-source $(d_s)_{s\in[1,N_s]}$ can be computed. This distance is also used to take into account the air absorption, by modifying equation (17) into :

$$E_s(f) \approx \frac{n}{N} e^{-\beta(f)d_s} \prod_{j=1}^{m} (1 - \alpha_j(f)), \tag{18}$$

with $\beta(f)$ a frequency dependent absorbing coefficient [1]. Furthermore, fixing the sound celerity c, room impulse response can be generated, converting each distance d_s in time of arrival. Taking care to convert energy into sound pressure ($p = \sqrt{E}$), finite impulse response can be generated and analyzed using standard metrics (e.g. T_{30}, C_{80}, D_{50}, etc.). For auralization, this room impulse response is convolved with an audio signal in order to listen the acoustical rendering. In particular, this convolution can involve relative position of predominant images sources, in order to realize a spatialized auralization with multichannel or binaural renderers. Finally, to complete acoustic studies with visual analysis, images sources can be projected on the room used for computation to see where are located listened reflections (see last impact on fig. 11).

5.2 Implementation

5.2.1 Standard algorithm

As standard principles are introduced, we focus now on the numerical implementation of an acoustic renderer by ray-tracing. Before any acoustic computation, a numerical room has to be modelized with surfaces and materials. In our case, we use the classical representation with mesh composed of flat triangles. Geometrical intersections are computed between rays (represented by oriented lines (L)) and mesh elements (represented by pieces of plans (P)), using parametric equations :

$$(L) \quad : \quad a + \delta \vec{u}, \quad \delta \in \mathbb{R}, \tag{19}$$

$$(P) \quad : \quad b + \lambda \vec{v} + \mu \vec{w}, \quad \lambda, \mu \in \mathbb{R}. \tag{20}$$

Considering $\vec{v}$ and $\vec{w}$ driven by two edges of each triangle, the following conditions give pairs (rays ;elements) with uniqueness :

- $(0 \leq \lambda \leq 1)$, $(0 \leq \mu \leq 1)$ and $(\lambda + \mu \leq 1)$ to ensure that the intersection is inside the triangle,
- $\delta > 0$ to respect the propagation direction,
- δ minimum not to go through the mesh.

Practically, to find these pairs, we can solve directly the underlying linear system or use the Moller-Trumber algorithm [10]. For N rays and M triangular elements, this process has a quadratic numerical cost (proportional to NM), which is critical if both N and M are large (see section **??**). Once all pairs are found, energy measurement has to be done in order to build images-sources (see section 5.1.4). To this end, the rays are intersected to the measurement sphere $S(x_m, r)$ using its cartesian representation :

$$(x - x_m)^2 - r^2 = 0, \quad \forall x \in \mathbb{R}, \tag{21}$$

which leads to a linear numerical cost proportional to N.

Finally, a ray is reflected according to equation (14) and propagated while its distance travelled verify condition (12). This iterative strategy ensure the energy propagation by the elimination of all rays that would be in non-measurable beams. In the particular case of an open-air room, rays which don't encountered surface of the mesh are also eliminated. Once all rays are eliminated, images-sources can be built and post-treated (room impulse response, auralization, etc.).

5.3 Perceptive factors

This section presents the perceptive factors as implemented in Just4RIR. In the following formulae, $E_{a\to b}$ is the sum of energy contributions between time a and time b after the direct sound such as :

$$E_{a\to b} = \int_a^b E(t)dt. \tag{22}$$

5.3.1 Reverberation time : *T30*

The reverberation time is measured by doubling the time frome -5 to -35dB. This extrapolation avoid perturbations at the beginning or the end of the signal. It comes from the decay curves which are obtained by inverse integration of Schroeder [14, p.410] on the echogram such as :

$$E'(t) = \sum_{\infty}^{t} E(\tau)d(-\tau).^{7} \tag{23}$$

In the case the impulse response stop before -35dB, decay curves are extended by linear regression to reach the threshold parameter.

5.3.2 Early Decay Time : *EDT*

As for *T30*, *EDT* is six time the time to go from 0 to -10dB on decay curves.

5.3.3 Clarty : *C80*

$$C_{80} = 10\log\left(\frac{E_{0\to 80}}{E_{80\to\infty}}\right). \tag{24}$$

5.3.4 Definition : *D50*

$$D_{50} = \frac{E_{0\to 50}}{E_{0\to\infty}}. \tag{25}$$

We can generally qualify the quality of a room by table 3 [8, p.59]

7. Norme ISO 3382 part 1 gives the formula : $E(t) = \int_0^{\infty} p^2(\tau)d(\tau) = \int_{\infty}^{t} p^2(\tau)d(-\tau)$.

D50	0 to 30%	30 to 45%	45 to 60%	60 to 75%	75 to 100%
Definition	Bad	Poor	Average	Good	Excellente

TABLE 3 – Evaluation of the Definition criteria.

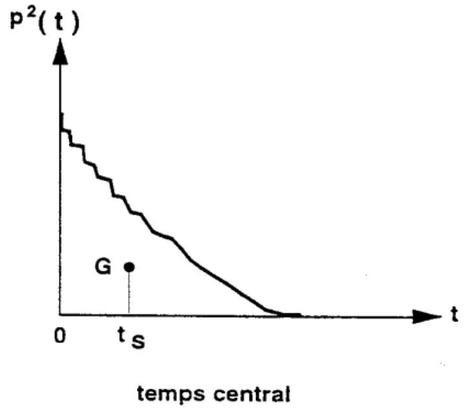


FIGURE 12 – Representation of central time *Ts* on the graph of energy to time.

5.3.5 Central time : *Ts*

$$T_s = \frac{\sum_{0}^{\infty} tE_t}{E_{0\to\infty}}. \tag{26}$$

5.3.6 Sound Pressure Level : *SPL*

The gain G in (dB) the room add to the sound is given by :

$$G = 10 \log E_{0\to\infty}. \tag{27}$$

SPL correspond to G when the direct sound at 10m has an energy equal to -31dB [8]. Then :

$$E'(t) = E(t)\frac{10^{-1,1}e^{-\beta(f)tv}}{(t.c)^2}, \tag{28}$$

avec :

- E′(t) : adapted energy to worth -31dB at 10m in free space,
- E(t) : normalized energy with direct sound = 0dB,
- $\beta(f)$: atmospheric absorption coefficient,
- c : speed of sound in medium (=340m/s for the air).

5.3.7 SpacmacOSity : *LF80*

$$LF_{80} = \frac{\sum_{t=5}^{80} E_t \cos^2(\gamma_t)}{E_{0\to 80}}, \tag{29}$$

where γ_t is the angle between the image-source to the axis linking both ears of the listener.

8. ISO 3382-1, 2009

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