Obscurant representation improvements in the CHORALE workshop

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ABSTRACT

CHORALE (simulated Optronic Acoustic Radar battlefield) is used by the French DGA/DET (Directorate for Evaluation of the French Ministry of Defense) to perform multi-sensors simulations. CHORALE enables the user to create virtual and realistic multi spectral 3D scenes, and generate the physical signal received by a sensor, typically an IR sensor. Some assessments concern the study of the duality between a threat (a missile for example) and a target (a battle tank for example) in the battlefield. In these cases, obscurants are special counter measures (clouds), classically used to hide armored vehicles and/or to deceive threatens. To evaluate their efficiency in visible and infrared wavelength, simulations tools, that give a good representation of physical phenomena, are used. The first part of this article describes the elements used to prepare data for the simulation. The second part explains the physical model used in CHORALE for the resolution of the Radiative Transfer Equation when obscurants are set in the scene. Obscurants are modeled by a set of voxels (elementary volume elements). Each voxel contains the spectral absorption and scattering coefficients, phase function coefficient and temperature information. The shape is changing with time to take into account the dynamic evolution of the obscurant. A “photon map” method is used in the ray tracing process to take into account global illumination within the cloud and solve the Radiative Transfer Equation.

Keywords: Simulation, ray tracing, infrared, obscurant, cloud, scattering, diffusion, radiative transfer equation, photon mapping.

1. INTRODUCTION

With an aim of evaluating the duel between threat as intelligent ammunition, missile and a main battle tank, it is necessary to use artificial smoke, pyrotechnical clouds in the scenario. In fact, the survivability of an armored vehicle on the battlefield is a criterion, which is schematized by a complementarity of means to avoid the multiple threats. The figure 1 shows the hierarchy of actions and solutions against threats.

At the sight of this figure, the present study falls under the evaluation of devices providing the following functions: "not to be detected", "not to be identified", and "not to be acquired". The two ways to carry out these evaluations are:

- In a passive way, with nets of camouflage or modifications of signatures by paintings.
- In an active way with the pyrotechnics countermeasures of masking, jamming or deception.

Thus to evaluate the capacity of masking of a pyrotechnical cloud, a solution consists in either testing it in true sizes when that is possible, or by digital models via tools for simulation. To characterize pyrotechnical clouds, the old version of CM-PYRO (pyrotechnical counter-measure software) was used. Today, the new version makes it possible to improve the prediction of the effectiveness of the smoke-producing devices by more accurately reflecting the physics of the phenomena in presence as well on the level of the atmospheric dispersion as of the radiative treatment of the cloud.
In each evaluating mission, we can organize threats by order of importance:

- Threat guided by infrared gap in two axes,
- Threat with a semi-active laser detector,
- Threat with an infrared seeker,
- Threat with a radar detector

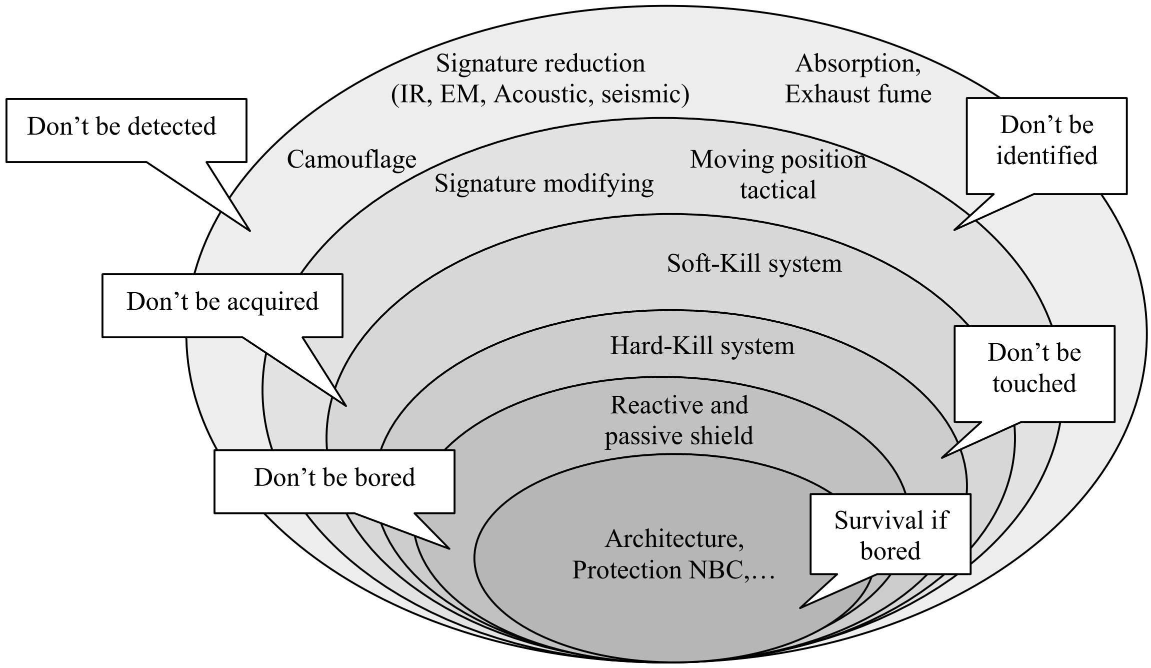

Figure 1: Hierarchy of actions and solutions against threats

CHORALE is the reference tool used by the DGA/DET. CHORALE makes it possible to carry out simulations of a virtual theatre of the battlefield relating to the optronic, radar and acoustic spectrum. This environment is a full compliance with the previous. Indeed the field of expertise concerns the evaluation of system related to tracking by optronic and/or acoustics devices, as well as the field of the intelligent ammunition able to rejoin a target indicated by a detection, guidance pilot unit. All simulation takes into account vehicles, airplane, smoke devices in the battlefield environment.

2. CLOUD DATA INPUT SETTING

Before using CHORALE workshop, we need to obtain some data according to the cloud process taking into account the wind, the temperature and each position of obscurant device on the ground. Several tools are necessary as FLUENT for the digital simulation of the atmospheric behavior. Then we obtain the concentration of the particles depending of the time. All components inside the smoke producer as material, sources, ammunitions are used in an intermediary software "preparation phase" which provides a file with radiative properties for each particles in the 3D grid.

As an example, we have considered a scenario with 8 obscurant devices. The aim is to know the behavior of these devices ejected from a Main Battle Tank, according to the wind and their specific positions.

a) Wind model and pyrotechnical devices positions
The atmospheric behavior is modeled by the wind and the air temperature profiles. For digital simulation, it is very important to define the flow method and field limit conditions. For the simulation, the wind is considered coming from the left side versus the Main Battle Tank axis and each pyrotechnical load are positioned as shown in figure 2:

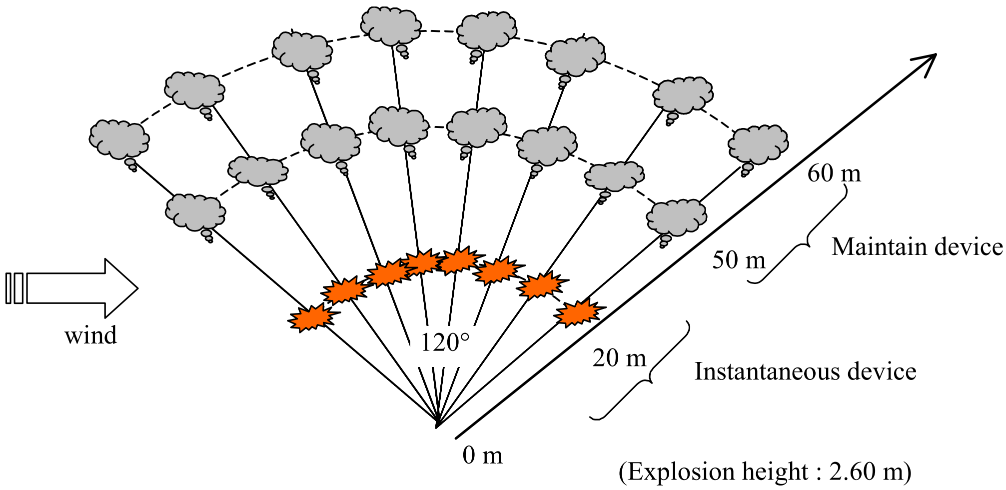

Figure 2: Example of positions of pyrotechnical devices

b) Operational theatre model

Figure 3 shows the operational ground model. Calculations, made by FLUENT, are limited within this model. Limit conditions are set as shown in figure 3. The size of this theatre is large enough to avoid the influence of the walls.

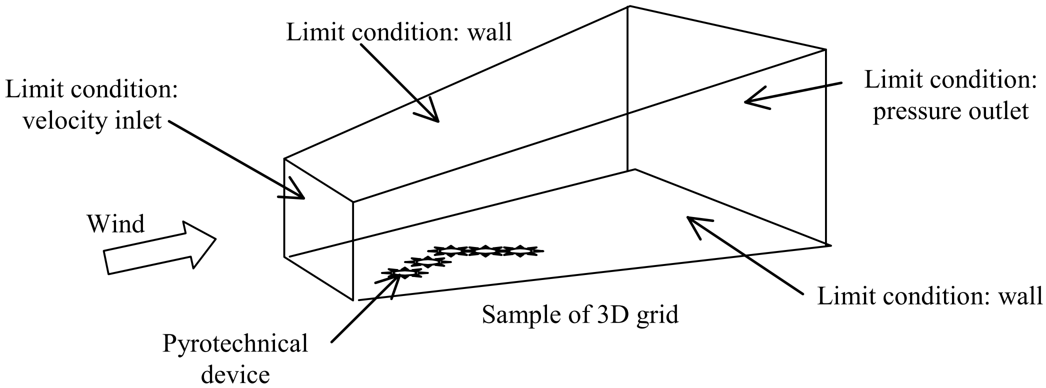

Figure 3: Operational theatre model

A 3D mesher, called GAMBIT, generates the used 3D-grid. Each maintained pyrotechnical device is modeled by a hemispheric shape to obtain a 3D model (cf. figure 4). After the computation, FLUENT provides results that depend on:

- the time of simulation,
- the type of particles,

and that take into account the turbulence (cf. figure 5). They represent the evolution of particle concentration during time. The “preparation phase” provides radiative properties of each particle.

In the case of an expertise of the smoke, the software computes the Radiative Transfer Equation.

In the other case, the result of the “preparation phase” is used to perform simulations in a 3D virtual scene using CHORALE.

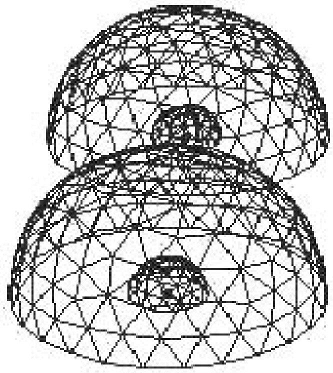

Figure 4: Hemispherical 3D model

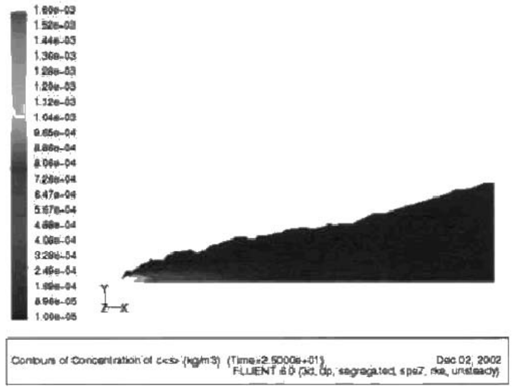

Figure 5: FLUENT results

The figure 6 shows the data streaming between the different software, the calculation of the diffusion inside the cloud via CHORALE is described in the continuation of this paper.

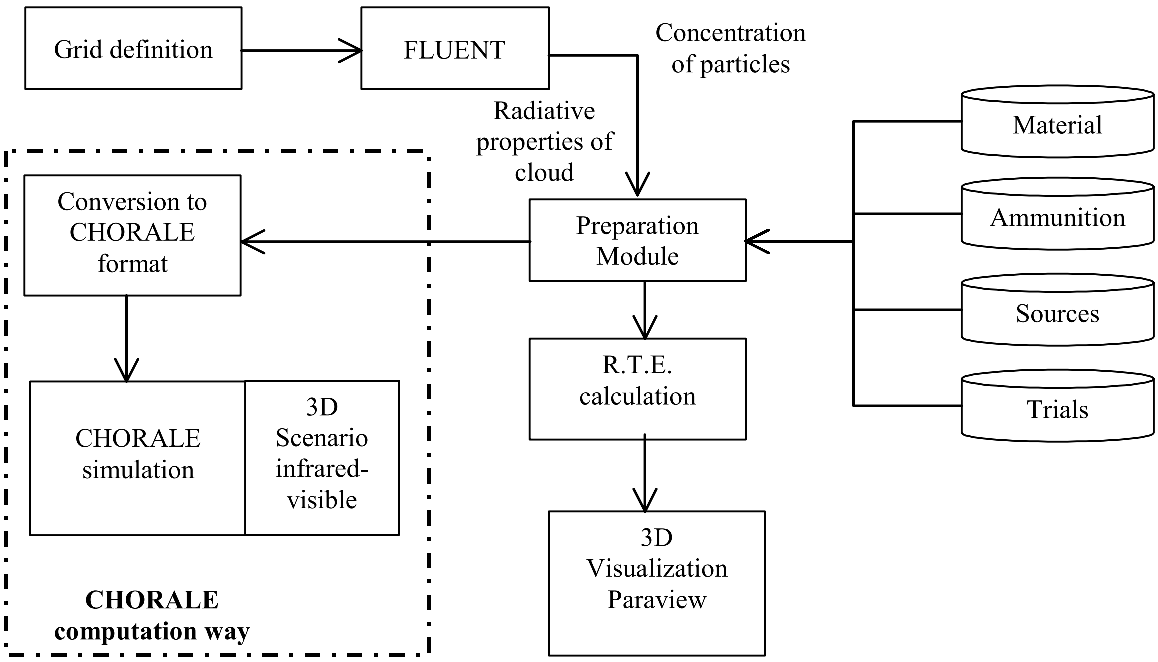

Figure 6: Architecture of simulation

3. PHYSICAL MODEL USED IN CHORALE

3.1. Obscurant representation in CHORALE

An obscurant is a modeled by a set of regular voxels (volume element). Each voxel is defined by spectral scattering and absorption coefficients $\sigma_s(\lambda)$ and $\sigma_a(\lambda)$, temperature T, and the spectral parameter $g(\lambda)$ of the Henyey-Greenstein phase function $p(g,\theta)$:

$$p(g,\theta)=\frac{1-g^2}{4\pi(1+g^2-2g\cos\theta)^{1.5}}$$

These data are spectral depending and time depending to simulate the obscurant expansion. Indeed, cloud representation contains time information in such a way that SPECRAY can animate a cloud object, interpolating, for each voxel (according to time), the radiance and attenuation values between the different representations. The cloud object must have a trajectory to be animated.

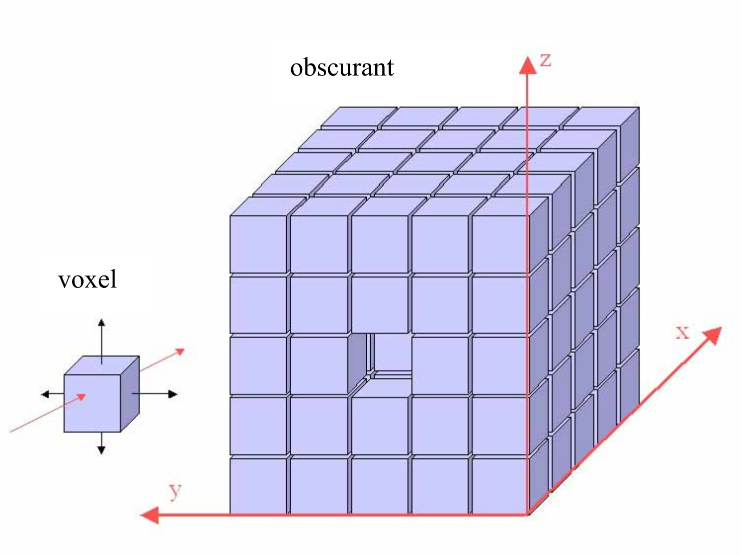

Figure 7: Obscurant representation using voxels

Time is necessary to represent smoke-producing phenomena or clouds that change their morphological characteristics (shape, molecular distribution, etc.) in time.

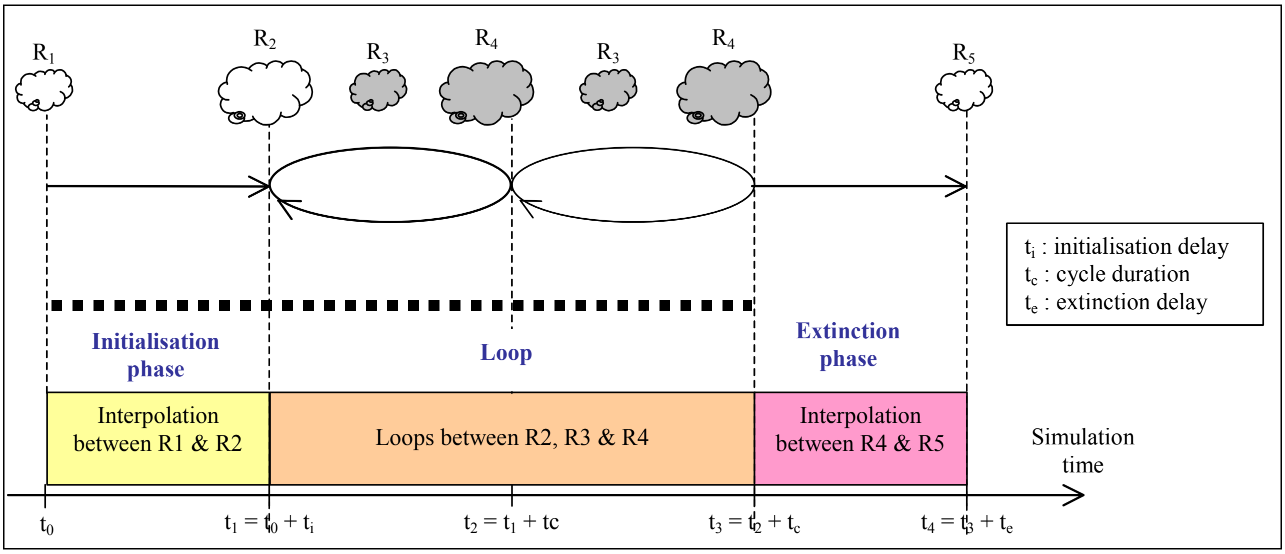

Figure 8: Obscurant representation according to the time

The cloud has an initialisation phase, representing the firing of a smoke-producing phenomena or the cloud formation; a cyclical animation phase; and an extinction phase. The end of the initialisation and the beginning of the extinction phases are identified by cloud representation indexes associated each one to a time, serving as boundaries between the evolution phases. The initialisation phase starts with the **activation** of the cloud and ends at the time supplied for its termination. After this time, the evolution phase starts and the animation loops between the cloud representation indexes explained above. When the cloud **deactivation** is triggered, the evolution continues with the first representation associated with the extinction phase, going on until the last representation, after which the cloud extinguishes definitively.

3.2. Radiative transfer theory in participating media

The propagation of light in a cloud (often called "participating media") is characterized by 3 phenomena:

- Emission: light energy that can be emitted by the media, particularly in the infrared domain,
- Absorption: light energy that can be absorbed by the media,
- Scattering: light energy that can be lost or gathered on the path of a ray. This phenomenon can be split into two cases. The first is the light energy lost on the path of a ray in the media, which is called "out scattering". The second is the light energy that is scattered by the media in the direction of observation, which is called "in scattering".

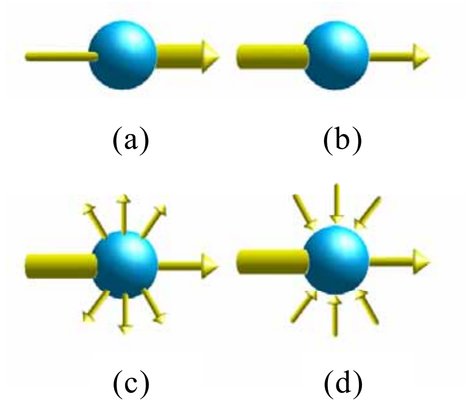

Figure 9: Phenomena affecting light propagation. (a) Emission.(b) Absorption. (c) Out-scattering. (d) In-scattering.

3.3. Volume Radiative Transfer Equation

The radiative transfer in participating media can be formalized by the volume transfer equation. This is the integral expression of the radiative transfer equation in participating media. Considering point x in the media as in figure 10, the radiance in direction ω_0, $L(x;\omega_0)$ is given by:

$$
\begin{aligned}
L(x;\omega_0) = {} & e^{-\tau(x_0,x)} L(x_0;\omega_0) \\
& + \int_{x_0}^{x} e^{-\tau(u,x)} L(x_0;\omega_0)\sigma_a(u) L_e(u)\,du \\
& + \int_{x_0}^{x} e^{-\tau(u,x)} L(x_0;\omega_0)\frac{\sigma_s(u)}{4\pi} L_\omega(u)\,du
\end{aligned}
\tag{1}
$$

with:

$L_\omega(x) = \int_{\Omega=4\pi} p(x,\omega_0,\omega_i) L(x,\omega_i)\,d\omega_i$: in-scattering radiance at point x,

σ_a : absorption coefficient (equal to the emission coefficient at thermodynamic equilibrium),

σ_s : scattering coefficient,

L_e : self emitted radiance at x,
$p(x;\omega_0;\omega_i)$: phase function,
$L(x;\omega_i)$: incoming radiance from direction ω_i.
$\tau(a;b) = \int_a^b \sigma_t(u)du$: optical thickness on the path $[a;b]$ with $\sigma_t = \sigma_a + \sigma_s$ the extinction coefficient.

The first term of equation (1) corresponds to the loss of energy due to absorption and out-scattering on the path $[x_0; x]$. The second and third terms correspond to the gain of energy due respectively to self-emission and in-scattering on the same path direction ω_i.

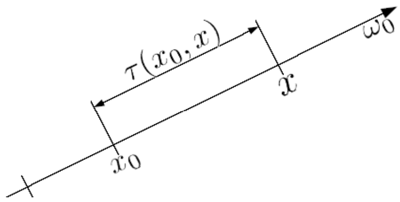

Figure 10: Geometry associated to the volume transfer equation

3.4. Photon mapping

The method used in CHORALE to solve the RTE in participating media is called Photon Mapping. It is a global illumination method based on particle tracing and density estimation. It is a two-pass method.
Firstly, the light is propagated through the participating media using standard ray tracing techniques. A virtual particle, called photon by analogy with the corpuscular theory of the light, is used to store energy at the interaction points of the light with the medium. When a photon enters a participating media, it interacts with it after a mean distance $\bar{d}$ of interaction depending on the optical thickness of the media:

$$\bar{d} = \frac{1}{\tau(0,\bar{d}_h)} \qquad \text{with} \qquad \tau(0,\bar{d}_h) = \int_M^{M+\bar{d}_h} \sigma_t(u)du$$

Then photons are absorbed, reflected or scattered using the Russian Roulette method which consists in randomly choose an event (absorption, reflection, scattering) according to the media properties (scattering albedo $\Lambda = \frac{\sigma_s(M)}{\sigma_t(M)}$).
If the photon is not absorbed, a new direction is chosen using importance sampling of the phase function (cf. figure 11).

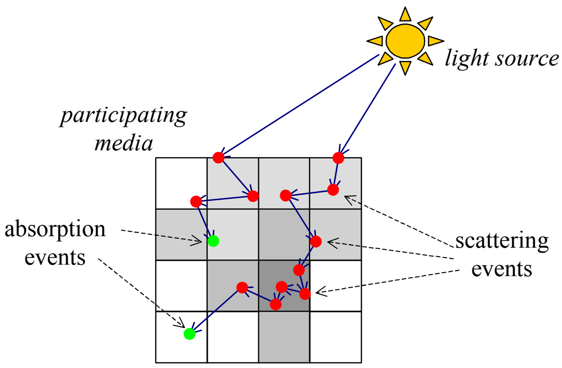

Figure 11: Photons propagation

Once the propagation phase was performed, the data structure obtained is called a photon map

The second pass consists of reconstructing the radiance seen by the observer by throwing a ray from the eye through the media. Then the radiance gathered by the ray is computed using a numerical integration scheme, i.e. cutting the ray in little segments for which radiance is evaluated by a recursive equation.

$$L(M,\vec{\omega}) = e^{-\sigma_t(M)\Delta l} L(M+\Delta l,\vec{\omega}) + \Delta l \sigma_a(M) L_e(M,\vec{\omega}) + \Delta l \sigma_s(M) \int_{\Omega'=4\pi} p(M,\vec{\omega}' \to \vec{\omega}) L(M,\vec{\omega}')d\omega'$$

For each segment, an evaluation point is chosen for computing the in-scattered radiance from the photon map. This is done using the *k*-nearest photons of the evaluation point. The radiance is computed as a mean of the nearest photon energy weighted by the phase function. (cf. figure 12). This method is called recursive Ray Marching.

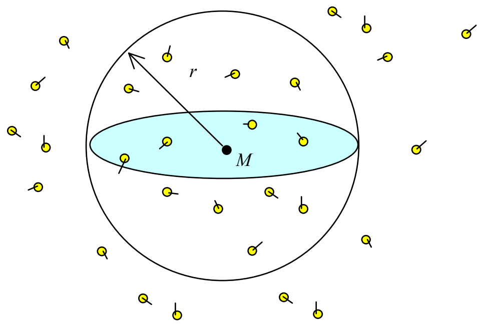

Figure 12: Nearest photons

4. VALIDATION

For some simplified and canonic cases, validation tests were performed and showed a good agreement between analytical solutions of RTE solving and ray tracing method (less than 10 % of difference between the 2 methods). Moreover, test trials are foreseen by French DGA. The results will be used to validate the simulation model.

5. PERSPECTIVE

The main evolutions concern the optimizations in term of time computation and memory allocation. A new algorithm, called “Photon splatting” is under study. The first result shows a significant gain of time computation. Another way of optimization is the use of the Graphic Processor Unit of some recent graphic boards of PC computers to perform some of the computations.

Figure 13: Example of simulation in the visible spectrum

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