Lighting simulation with the presence of fog : a real time rendering solution for driving simulators

P. Lecocq[*] — S. Michelin[**] — A. Kemeny[*] — D. Arquès[**]

*Renault – Engineering Development Department
TCR AVA 2 12, 1 avenue du Golf, 78288 Guyancourt Cedex
Phone : +33 1 34 95 19 85 – Fax : +33 1 34 95 27 30
Email: {pascal.lecocq, andras.kemeny}@renault.com

**University of Marne-la-Vallée
5 Boulevard Descartes, Champs-sur-Marne, 77454 Marne-la-Vallée Cedex 2
Phone : +33 1 60 95 77 31 – Fax : +33 1 60 95 75 57
Email: {michelin, arques}@univ-mlv.fr

Abstract

Lighting simulation applications for driving simulation [LC00][LM01] are now widely used to test and assess performances of new car headlights. Renault was one of the first to develop a night driving simulator for headlight studies [LK99]. Today, available driving situations are clear night situations. Clear night is not sufficient in some cases to evaluate all the aspect of headlight design. One example of such an impact is the apparition of light beam spreading in foggy driving condition. This phenomenon comes from the interaction between light and fog water droplet and can be disturbing for the driving task. Headlight study in such conditions is difficult because fog is not easy to get in real life. Our objective is to implement this phenomena in a driving simulator to overcome this difficulty.

In this paper, we propose a real time solution with no assumption on the point of view and headlight positions. The solution relies on mathematical approximations based upon a re-formulation of the light transport equation governing light exchange within participating media [LM00]. Combined with a 2D rendering technique, the method avoids the real-time constraint for any image size. Our solution can be applied for the oncoming traffic headlights as well as for driver's headlight.

Résumé

L'utilisation de la simulation d'éclairage en simulation de conduite est aujourd'hui largement répandue pour tester et valider les projecteurs des futurs véhicules automobiles. Renault fut l'un des premiers à développer un simulateur de conduite de nuit pour l'étude et la mise au point de nouveaux projecteurs. Seule la conduite de nuit par temps clair est considérée. Ce type de condition est insuffisant pour évaluer tout les aspects d'un projecteur. Certains de ces aspects peuvent s'avérer gênant pour la conduite. L'apparition de voiles lumineux devant le conducteur par temps de brouillard en est un exemple. L'apparition de ce voile provient de l'interaction entre la lumière issue des projecteurs et les particules d'eau en suspension constituant le brouillard. L'étude des projecteurs dans ces conditions n'est pas aisée car le brouillard est difficile à appréhender dans la réalité. Notre objectif est de simuler ce phénomène dans un simulateur de conduite pour palier à cette difficulté.

Nous présentons dans cet article une solution temps réel pour visualiser les voiles lumineux sans aucune restriction sur le point d'observation ni sur le positionnement des projecteurs. La solution repose sur des approximations mathématiques développées à partir d'une simplification de l'équation de transport qui régie les échanges lumineux dans les milieux participants. Combinée avec une technique de rendu 2D, la solution lève la contrainte temps réel quelque soit la résolution de l'image. Cette solution peut être appliquée pour visualiser les voiles issus des projecteurs du conducteur mais aussi pour visualiser ceux des véhicules du trafic.

Motivations and Objectives

The real time lighting simulation challenge in the industry

Designers of lighting systems want to anticipate well in advance light design characteristics in order to reduce cost and delay in prototype design. Lighting simulation is a way to achieve this work. Classic realistic lighting simulation software are based upon global illumination models where pictures can be obtained after several hours of computations. With the improved performance of 3D accelerated computer graphic boards, simple lighting calculations can be done in real time through dedicated hardware functions. Real time lighting simulation software is becoming a requirement in the lighting industry because lighting experts want to evaluate their products in different conditions and orientations.

Real time lighting simulation for headlight rendering

Driving and flight simulators have been the first to exploit 3D accelerated graphic boards capabilities for real time rendering of the visual environment. Renault was one of the first to introduce real time rendering of road lighting in a driving simulator [LK99]. The rendering solution is based on a multi-pass rendering algorithm which takes advantage of hardware accelerated texture projection of high-end graphic boards to bring realistic rendering of light beams.

Figure 1 : Renault lighting simulator (driver's view)

Figure 2 : Headlight photometric description (false colour)

Outgoing light distribution of headlights is described by photometric measurements taken from physical headlights or from a numerical description of headlight (figure 2). In the numerical case, measurements are done by light travel simulation inside the optical block by the use of Monte Carlo based algorithms.

Nights test have been replaced by virtual night tests on Renault driving simulator for new car headlight studies. Benefits of such a tool are numerous. First, it saves cost and money since no more physical headlights are needed. Moreover, working conditions are improved since there is no more need to wait for the night fall. And last, it allows the study of new advanced front lighting system for cars [LC00].

Rendering realistic fog condition for driving simulation

Renault real time lighting simulation tool allows fast evaluation of headlight performances in clear night situation. However, in the case of bad weather condition, some lighting effects can not be visualised with virtual night tests. One example of such lighting effects is the apparition of light beam spreading when fog is present. This phenomenon can be very disturbing for the driving task. However, night tests with fog condition are not easily done in real life. Implementation of this phenomenon in a driving simulator is a solution for this problem.

In the following paragraph we present a solution for real time visualisation of light beams coming from the light interaction between headlights and fog. To understand the phenomenon, we make an introduction to the light transport theory within fog and we propose a review of existing fog rendering solutions in a first part. In a second part, we present a new formulation of the light transport equation with an approximation for fast computations. A last we present a spatial coherence based rendering solution for real time rendering of light beams within fog.

Lighting simulation in presence of fog : theory and rendering solutions

The light transport equation

Illumination of the participating medium is the result of the interaction between the light and particles which compose the media. The light interaction within a participating media is expressed by the light transport equation. The light transport equation is given by a differential equation expressing the variation of luminance along a ray path in a participating medium. Four interactions are taken into account in the light transport equation : absorption, scattering, emission and in-scattering.

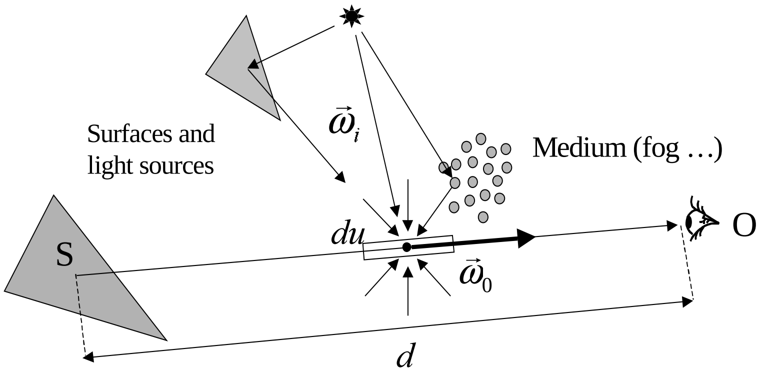

Figure 3 : Light interactions within a participating medium

Integral expression of the light transport equation following figure 3 notation is given by :

$$L(O) = \tau(0,d)L(S) + \int_0^d \tau(0,u)K_t(u)J(u)du \quad (1)$$

with

$\tau(0,d)$	Transmittance.

$J(u)$	Source radiance function.
$L(S)$	Luminance leaving S in the $\vec{\omega}_o$ direction.
$L(O)$	Luminance reaching observer O coming from $\vec{\omega}_o$ direction.

$J(u) = J_a(u) + \frac{\Omega(u)}{4\pi} \int_{\Theta} L_i(u, \vec{\omega}_i) \phi(\vec{\omega}_i, \vec{\omega}_0) d\omega_i$ is the *source radiance* expressing the energy contribution coming from all directions scattered in the $\vec{\omega}_o$ direction according to a scattering phase function $\phi(\vec{\omega}_i, \vec{\omega}_0)$.

Rendering solutions

Solving the light transport equation for non real time image rendering has been intensively studied for several years. Solving methods can be classified in two categories [PP97]: stochastic methods and deterministic methods.

Stochastic methods

Stochastic methods relies on Monte Carlo method to integrate the light transport equation. Rays with random directions are sent through the scene either from light sources (shooting techniques) [BL93][JC98] or from the observer (gathering techniques). Combination of both can be employed for best results [LW93]. The main problem of Monte Carlo based techniques is that a high number of rays has to be sent in order to obtain images with low noise. However, increasing the ray number, increases the rendering time which is far from real time.

Deterministic methods

Deterministic methods rely on finite element techniques to solve the light transport equation. Most of them consists in the subdivision of participating media into small finite elements. Zonal [RT87] or spherical harmonic methods [KV84] can be applied for radiative transfer simulation. Other solutions rely on ray-tracing techniques [NM87] based on a ray-marching technique. These solutions consist in the subdivision of ray into small path elements where light interaction with participating media is computed and sum up along the ray. Unfortunately, rendering times are prohibitive for real time application.

Real-time rendering solutions

Real time solutions have been proposed taking advantage of graphic hardware capabilities. A real time solution is implemented in most 3D computer graphic boards [WN99] but it simply considers the attenuation of light by absorption. Another solution proposed by Dumont and al [DFG00] consists in the pre-computing of light beam images from driver's point of view. The image is then encoded in a 2D hardware texture for real-time rendering. However, the light beam remains static during the simulation. Dobashi and al [DY00] proposes a solution using accumulation of virtual plane where the light interaction is computed at plan vertices. Color of each plan is combined with a projected texture technique describing the light source directivity. Lots of plan are needed to avoid aliasing effects and rendering times are not sufficient for the driving simulation context.

From this statement, we propose a new real time solution which is view independent and suitable for driving simulator application.

Polynomial approximations of light transport equation

Due to the light transport equation complexity our method is based on a simplified transport equation given by Nishita and al in 1987 [NM87]. A reformulation and polynomial approximation of this equation is proposed for fast luminance computations.

Simplified Nishita's light transport equation

The simplified Nishita's light transport equation considers point light sources with an arbitrary luminous energy distribution. The medium is assumed to be homogenous and the multi-scattering phenomenon is neglected.

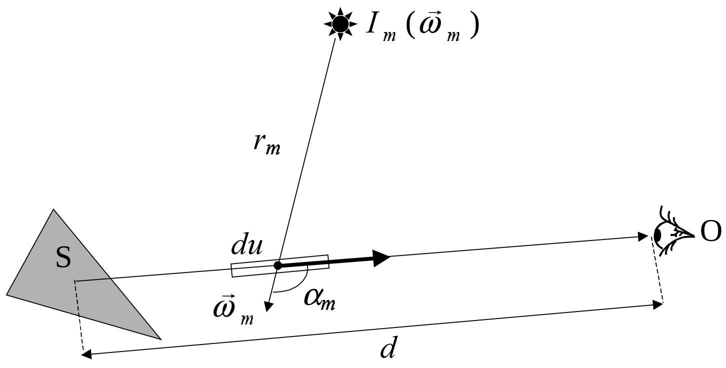

Figure 4 : geometry associated with simplified Nishita's light transport equation

From these assumption, the light transport equation becomes according figure 4 notations :

$$L(O) = e^{-K_t d} L(S) + \frac{\Omega}{4\pi} \sum_{m=1}^{N} \int_0^d e^{-K_t u} . K_t . e^{-K_t r_m(u)} \frac{I_m(\vec{\omega}_m(u))}{r_m(u)^2} \phi(\alpha_m(u)).du \qquad (2)$$

Reformulation of simplified light transport equation

Let's consider only one light source for notation simplification. We first propose to express the previous equation into angular variation upon a given direction in the (OIS) plan.

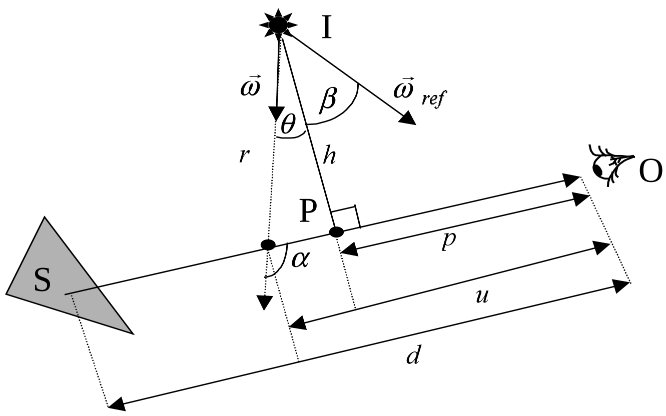

Figure 5 : geometry associated to the reformulation of the simplified light transport equation

According to figure 5 notations, we have $u = p + h\tan\theta$ and the simplified light transport equation thus becomes :

$$L(O) = L(S).e^{-K_t d} + K_t.\frac{\Omega}{4\pi}.\frac{e^{-K_t p}}{h}\int_{\theta_0}^{\theta_d} e^{-K_t h\left(\frac{\sin\theta+1}{\cos\theta}\right)} I(\theta+\beta)\phi\left(\theta+\frac{\pi}{2}\right)d\theta \qquad (3)$$

where θ_0 and θ_d represents angular limits when $u = 0$ and $u = d$.

Polynomial approximation

Let's consider the integral term :

$$G(h,\theta,K_t) = e^{-K_t h\left(\frac{\sin\theta+1}{\cos\theta}\right)}\phi(\theta+\frac{\pi}{2})$$

Since the term θ has low variation around 0 in the domain $\left[-\frac{\pi}{2};\frac{\pi}{2}\right]$, we propose to expand G according a polynomial approximation around $\theta = 0$. This gives us :

$$L(O) \approx L(S)e^{-K_t d} + K_t\frac{\Omega}{4\pi}\frac{e^{-K_t p}}{h}\left[\begin{array}{l} c_0(K_t,h)\int_{\theta_0}^{\theta_d} I(\theta+\beta)d\theta + c_1(K_t,h)\int_{\theta_0}^{\theta_d}\theta I(\theta+\beta)d\theta + \\ c_2(K_t,h)\int_{\theta_0}^{\theta_d}\theta^2 I(\theta+\beta)d\theta \end{array}\right] \qquad (4)$$

where c_0, c_1, c_2 are constant terms depending only on extinction coefficient K_t and h term.

Finally, we get a simple expression depending only on light distribution along a ray and depending on angular variation. For point light sources with homogenous luminous energy distribution an analytic solution can be found. For light sources with luminous energy directivity pre-computations are done in several tables for constant time evaluation of integral term.

Rendering : luminance computation

To speed-up luminance computation upon previous equation, we make a distinction between light contribution coming from surfaces and light contribution coming from light interaction with the participating media.

We put $L(O) = L_s(O) + L_m(O)$

where

$L_s(O) = L(S)e^{-K_t d} + I_a\left(1 - e^{-K_t d}\right)$ gives surfaces luminance contribution and $L_m(O) = K_t\frac{\Omega}{4\pi}\frac{e^{-K_t p}}{h}\left[c_0(K_t,h)\int_{\theta_0}^{\theta_d} I(\theta+\beta)d\theta + \ldots\right]$ gives participating medium luminance contribution.

The first term $L_s(O)$ is computed by 3D accelerated graphic board using projective texture technique [LK99] and the hardware exponential fog function in a first pass.

The second term is computed using polynomial approximations. Angular limits are computed using z-buffer information extracted from computer graphic board frame-buffer. However, luminance computations must be done for each pixel and this may be prohibitive for real time image rendering. In order to limit computation, we reduce the pixel number by image sub-sampling using a coherence technique based on light propagation characteristics.

Results

The following images are extracted from a real time driving simulation scene with different viewpoints. The scene contains two directional light sources associated with headlights and five homogenous light sources. Rendering times are around 30 Hz on a bi-pentium III 800 Mhz with a GeForce II GTS computer graphic board.

Figure 6 : Real time fog simulation images. Rendering time is around 30 Hz.

Conclusion and future works

A real time visualisation of light beam spreading in foggy atmosphere has been implemented. The solution is view independent and allows real time headlights positioning during a simulation. For driving simulator, it allows the visualisation of light beams coming from driver's headlights as well as coming from oncoming traffic. The next step will be to consider the light multi-scattering phenomena which is not taken into account in our method. The second step will be to consider area lights. This task is important because the assumption of point light sources is not valid near the headlight origin. Validation of beam spreading rendering will be therefore carried out according to physical and perceptual measurements.

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