Interactive Headlight Simulation

P. Lecocq, J-M. Kelada, A. Kemeny

Renault Direction de la Recherche - *Research Department*

Technocentre Renault TCR AVA 2 12
1, av du Golf 78288 Guyancourt Cedex – France
Phone : +33 1 34 95 19 85 Fax : +33 1 34 95 27 30
E-mail : Andras.Kemeny@renault.fr

Abstract

Headlight simulation has been recently studied for the conception of a new car projector by automotive car makers and suppliers. It allows the study of a supplier's numerical solution without making a physical prototype. Unfortunately, simulations are difficult to implement in real-time, computed by ray-tracing algorithms [1,2] or radiosity techniques [3], and are often visualized on a small screen. Consequently, the operator can seldom test his simulated projector in driving conditions. In order to have an interactive simulation, computer generated images need to be rendered in real-time. The real-time constraint implies the use of graphics hardware engine and optimized lighting models. However the choice of the lighting model is critical because of the necessity of high-level image quality in rendering the light distribution of the projector.

Renault, Direction de la Recherche, has recently developed such interactive headlight simulation software. Several parameters can be set in real-time, such as the position and the orientation of the headlamp. It is also possible to provide photometric simulated measurement data on the road during the simulation. The light distribution of the projector is taken into account according to its photometric description. More precisely, a projector is assimilated to a positional light source that delivers correct attenuation. The photometric description (in Lux) of the headlamp is encoded in a texture [6] which modulates the effect of the light source on a polygonal surface. Thus, the precision of the simulation directly depends on the level of precision of the photometric description and the level of detail of the scene in term of polygons. The headlight simulation software was integrated in Renault's driving simulators in 1998 and validated by Renault's photometric laboratory.

Résumé

La simulation d'éclairage est utilisée depuis peu par les compagnies automobiles et équipementiers pour étudier et concevoir de nouveaux phares. Elle permet d'étudier des propositions de phares sans la fabrication de prototypes physiques. Malheureusement, la plupart des simulations, utilisent des techniques de lancé de rayon [1,2] ou de radiosité [3] difficiles à implémenter en temps réel. D'autre part, les simulations étant souvent visualisées sur de simples moniteurs, l'opérateur ne se trouve pas immergé dans le poste de conduite rendant plus délicate l'évaluation du projecteur. La contrainte temps réel impose l'utilisation de matériel dédié à l'affichage graphique et l'utilisation de modèles d'éclairage appropriés. Cependant, le choix du modèle d'éclairage est critique en raison du degré de précision nécessaire pour rendre la distribution photométrique d'un phare.

Renault, Direction de la Recherche, a récemment développé un logiciel de simulation de phare interactif. Plusieurs paramètres peuvent être modifiés tels que la position et l'orientation des projecteurs. Il est également possible de prendre des mesures photométriques sur la route durant la simulation. La distribution lumineuse du projecteur est prise en compte à partir de sa description photométrique. Plus précisément, un phare est assimilé à une source de lumière ponctuelle délivrant l'atténuation sur la route. La description photométrique du projecteur est ensuite codée dans une texture [6] modulant l'effet de la source ponctuelle sur les surfaces. Ainsi, la précision de la simulation dépend directement du niveau de précision de la description photométrique du phare et du niveau de détail de la scène en terme de polygones. Le logiciel de simulation de phares a été intégré dans les simulateurs de conduite de Renault en 1998 et validé par les experts en éclairage chez Renault.

INTRODUCTION

The design of a new car headlamp implies the conception of several prototypes and night tests according to the evolution of car styling. These prototypes and night tests are required for testing the performance validation of the lamp in driving conditions. Several criteria are studied during these tests: the light distribution on the road, lighting homogeneity, far visibility. These tests are carried out a high number of times with the contribution of professional testers. Renault’s Research Division has developed a real-time lighting simulation tool integrated in a driving simulator. This tool aims at reducing design cost and delay of new headlamps with lesser number of prototypes and night tests.

In this paper, the headlight simulation software is presented. First an overview of computer graphics techniques for lighting simulation is given, followed by the description of Renault’s interactive lighting simulation software. Techniques employed to simulate in real-time headlamp’s lighting distribution on a road are detailed and the validation process is described.

OVERVIEW OF COMPUTER GRAPHICS TECHNIQUES

Computer graphics techniques for lighting simulation have evolved together with computer technology. The progress has allowed to provide lighting illumination models more and more complex and physically correct. Now the *light transport and interaction* physic laws are well known and are applied in rendering methods like ray-tracing[1,2], radiosity[3] or Monte-Carlo[2] techniques. Unfortunately the implementation of these algorithms into real-time simulation applications is difficult.

In parallel, the evolution of dedicated graphics hardware workstations allows the real-time rendering with a high number of polygons, hardware implemented lighting models and texture mapping. Therefore multi-pass algorithms has been developed to take advantage of these capabilities in order to provide real-time complex lighting rendering. The headlight simulation software uses these algorithms.

THE INTERACTIVE HEADLIGHT SIMULATION SOFTWARE

The Renault's interactive headlight simulation software a part of the driving simulation visualization software.

Overview of the driving simulator configuration

Renault's driving simulator [4,5], for lighting simulation is composed of a real vehicle cockpit. Different modules communicate together to compute and render driver's actions in the cockpit as illustrated in figure 1:

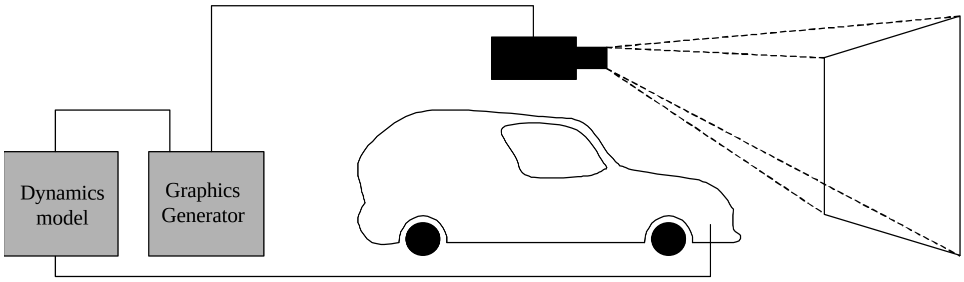


Figure 1: Driving simulator configuration

The visualization generates images at 30 to 60 Hz for a forward field of view of 150° and rear view mirrors. Experimentation using lighting simulation today is limited to a mono-channel configuration due to rendering complexity and the limits of the used one pipeline SGI InfiniteReality hardware. During the simulation session, the driver has the possibility to switch from low beam to high beam from the cockpit in the same way he or she would do in a real car. In addition, unlike in a real car, the driver has also the possibility to switch from one light beam design to another.

The illumination model

For real-time simulation the following constraints have been introduced in illumination model:

- Headlamp is assimilated to a white point light source with non-homogenous luminous intensity distribution.
- Light reemission of surfaces is not taken into account.
- Surfaces are diffuse.

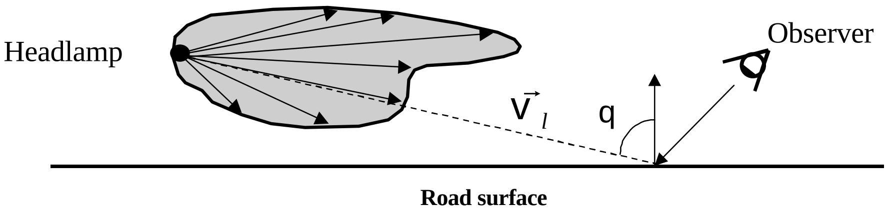


Figure 2: Non-homogenous point light source

Thus the illuminance coming from the headlamp reaching a surface can be written according to the Lambert’s law as follows:

$$E = \frac{I(\vec{\omega}_l).\cos\theta}{r^2} \qquad (1)$$

with:
E : illuminance (Lux),
$I(\omega_l)$: Intensity of the light source in direction ω_l (Candela),
θ : the angle between the surface normale and ω_l, direction of incident light.
r : distance between source and surface point (m).

Therefore, the observed luminance is:

$$L = \frac{\rho.E}{\pi} \qquad (2)$$

with:
L : luminance (Candela/m²),
ρ : surface reflectance (constant for diffuse surfaces),
E : illuminance (Lux).

The main task is the modeling of the light source luminous distribution. Due to the complexity of a headlamp, it is difficult to provide a mathematical model of the luminous distribution.

Photometric headlamp description

A car lamp is generally composed of several mirrors and striated glasses producing a given light distribution. For the sake of convenience, lighting simulation characteristics of the lamp are taken from measurements of the exit illuminance of the lamp. There are two manners to obtain measures of the exit headlamp illuminance.

A physical headlamp is placed onto a *goniometer*, and a *photometric cell* placed at a given distance measures the illuminance coming from different directions given by the goniometer.

Limitations:

Measurement of the outgoing illuminance is not sufficient to address the entire characteristics of a lamp. Due to the structure of the headlamp, multiple reflexions can occur inside the lamp. The lamp therefore acts as multiple small light sources that produce light emission with different directions as illustrated in Figure 3. However, the luminous distribution is considered to be totally formed at the considered observation distance.

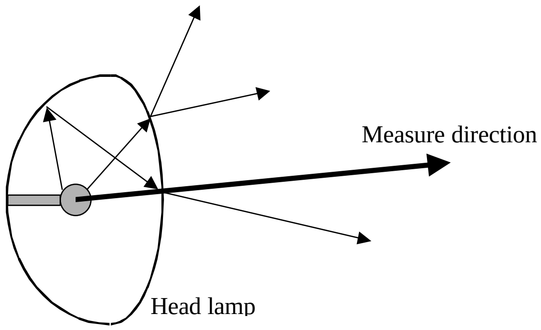


Figure 3: light path inside the lamp

Multipass rendering algorithm

For a satisfactory real-time lighting providing the required light distribution on the road, accurate light and surface characterisation has to be done.

Using hardware implementation of a multi-pass rendering technique of projected textures, the light distribution is defined by

$$I(\vec{v}_l) = I_{\max}.F(\vec{w}_l) \quad \text{with} \quad 0 \le F(\vec{v}_l) \le 1 \qquad (3)$$

where $F(\vec{v}_l)$ is the normalized luminous intensity distribution. The normalized luminous intensity distribution is directly encoded in a texture.

Therefore, the lighting on the road can be seen as the result of the lighting of the homogenous point light source, in a first rendering pass, modulated by the projected texture in a second rendering pass (figure 4).

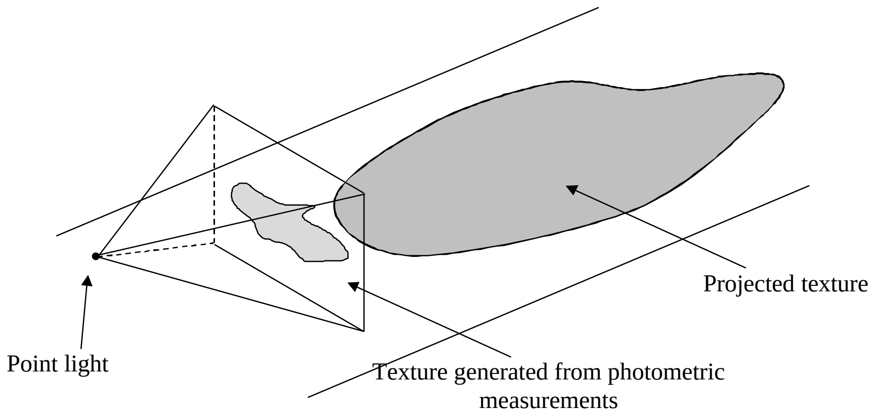


Figure 4: Multi-pass rendering with projected texture

Constraints on the visual database description

The lighting pass must be performed using a conveniently defined road sampling level-of-detail. In fact, as lighting calculations are done at each vertex in the database, the results depend on the database sampling. On the other hand, the use of a too high level-of-detail in database description implies a large collection of polygons result in slowing down image frequency.

A compromise solution relies on the definition of level of details on the road. Levels of detail provide more or less precise polygon description of the road as illustrated in Figure 5.

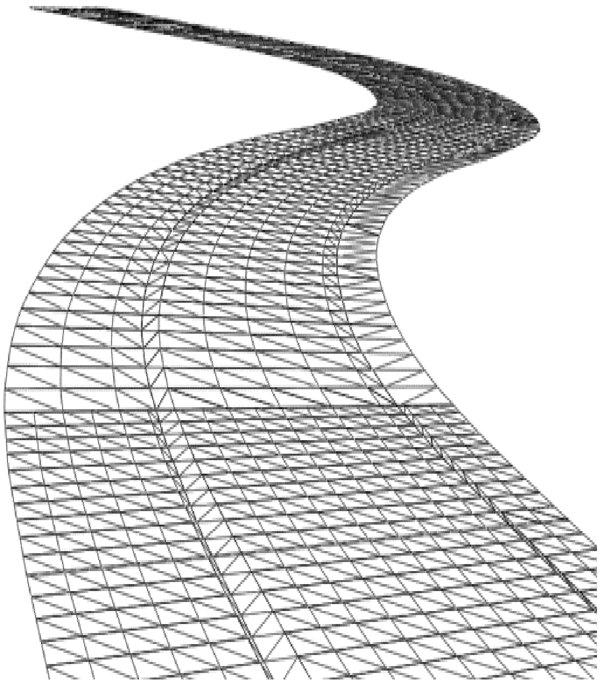


Figure 5: Definition of level of detail for road description

PERFORMANCES

The headlight simulation software runs on an Onyx InfiniteReality with one pipe and two R10000 processors (250 Mhz). Two projected textures are employed during the simulation (one for each headlamp). The software runs between 20 Hz and 30 Hz frame-rate according to the vehicle position in the database.

THE TOOLS

Different user interfaces and peripheral devices are integrated in Renault's driving simulator to take advantage of the simulation.

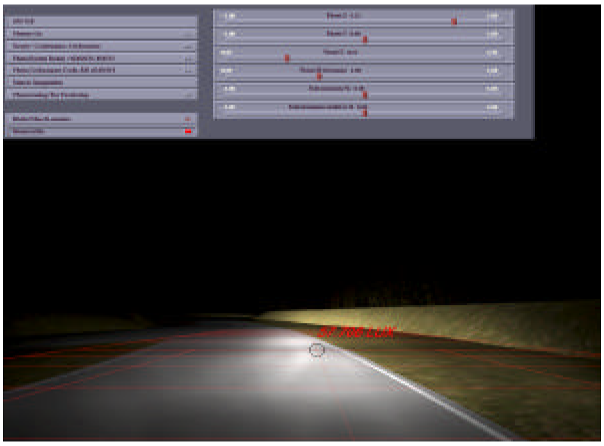
- The first set of tool controls the headlamp positioning through a *Graphical User Interface*. The following parameters can be changed in real-time:

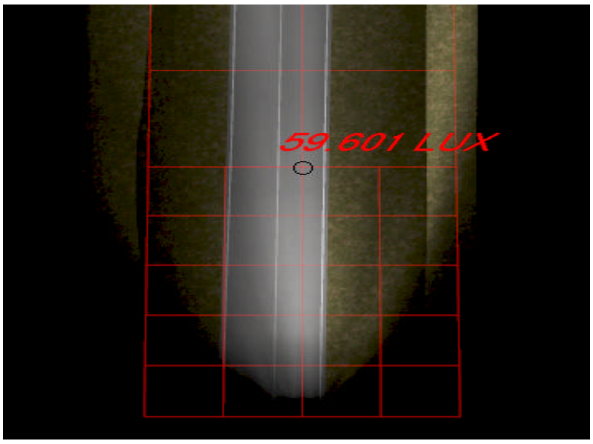
- Left-right and front-back head lamp positioning
- Altitude of lamps
- Pitch of lamps
- Space between lamps

Consequently it allows an easy positioning the lamps anywhere on the car to simulate for example fog lamps.

- The second set of tools allows the use of different points of view through user defined camera positioning. New cameras can be added and manipulated during the simulation providing for example aerial point of view for the observation of the light distribution on the road.

- The third set of tools provides simulated measurements. First a graduated grid in front of the vehicle is applied on the road. It allows estimating light distribution and range. Moreover the user has the possibility to take photometric measures (in Lux) anywhere on the road with a mouse connected to the workstation.





VALIDATION

The validation of the headlight simulation software was done through comparison with real car headlamp illumination.

Several headlamps have been used to validate the simulator. Physical measurement and computed measurements for the photometric description have been compared. Renault's driving headlight simulator has been validated in 1998 by Renault's photometric laboratory.

CONCLUSION & FURTHER WORKS

The headlight simulation tool provides the necessary information to compare several headlamp performances. It allows the reduction of the number of prototype and night tests. Further works on the lighting simulation software will consist in the improvement and complet the lighting models according the following objectives:

- To provide precise characterization of reflectance of surfaces
- To take into account light source colors
- To simulate different weather conditions simulation (fog, rain, snow, …)
- To generate blooming effect simulation

Moreover, the use of PC based solutions for rendering the lighting simulation is investigated.

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