7. International Immersive Projection Technologies Workshop
9. Eurographics Workshop on Virtual Environments
J. Deisinger, A. Kunz (Editors)

Real-Time Representation of Complex Lighting Data in a Nightdrive Simulation

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Abstract

For the development of new automobile lighting systems, special raytracing methods are used to completely simulate the illumination properties of the new product. For further evaluation, real test drives with real prototypes are still necessary. But changing weather and lighting conditions make the test drive results not fully comparable. Therefore, a high number of test drives have to be performed. This leads to a time-consuming and cost-intensive development process. Virtual test drives at night combined with a realistic simulation of a lighting system's illumination characteristics can minimize the number of real nightdrives and allow reproducible testing conditions as well as comparable results. A close-to-reality simulation poses high demands on the real-time method for calculating and displaying illumination data in a virtual scene. This paper introduces a real-time illumination method for use in a nightdrive simulation.

Keywords:
Headlight development, light simulation, luminance distribution, virtual reality, VR.

Categories and Subject Descriptors (according to ACM CSS): I.3.7 [Computer Graphics]: Virtual Reality; J.2 [Physical Sciences and Engineering]: Engineering

1. Introduction

Driving a car under difficult lighting conditions - due to bad weather or at darkness - increases the accident hazard to a high level. In Germany over 90 percent of car drives with headlights are done using low beam light, due to the high volume of traffic. The demands of an optimal luminance distribution depend in a high degree on the current driving situation, traffic conditions, and street characteristics [10]. As a result, the primary purpose of new innovative headlight systems is to increase traffic safety - especially at night. To achieve this, optimal luminance distributions depending on driving and surrounding conditions have to be provided.

The desire for situation-dependent adjustment of the luminance distribution leads to technically high integrated assemblies. A CAD-model and a prototype of a modern headlight system is shown in figure 1. To meet the various demands these assemblies need to have exact defined lighting features.

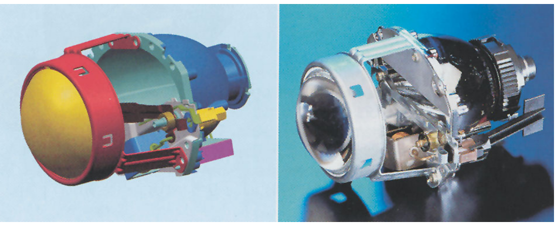

Figure 1: *Modern headlight-module with five shiftable light distributions (Source: Hella KG Hueck & Co.)*

To achieve the demanded light quality, a headlight system's luminance distribution is analysed and optimized using dedicated raytracing techniques (see figure 2). To represent complex luminance distributions correctly, specialized raytracing programs are needed [3]. Based on the headlight's CAD-model the raytracing software tracks the light beams starting from the light bulb via the reflector through the front glas onto a measurement wall in 10 meters distance. As the reflector surface itself consists of up to several thousand NURBS-faces, the light can be reflected several times within the headlight before it shines onto the measurement wall.

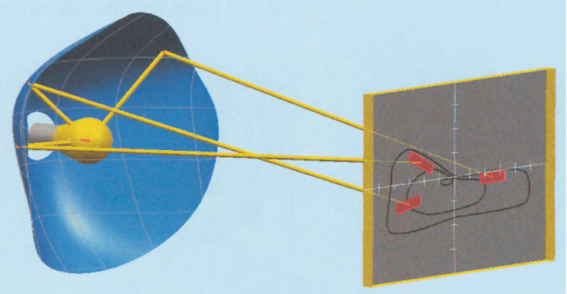

Figure 2: *Computation of a luminance distribution using raytracing (Source: Hella KG Hueck & Co.)*

The result of this process is a luminance distribution (see figure 3) defining the complex lighting characteristics of the headlamp.

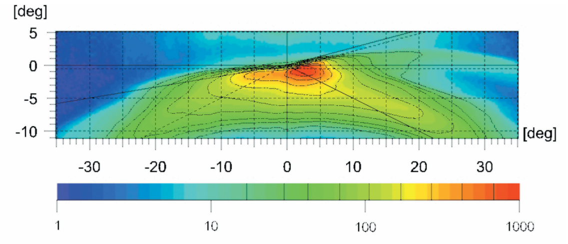

Figure 3: *Complex luminance distribution of a headlight system (Source: Hella KG Hueck & Co.)*

Based on the luminance distribution, the engineer can evaluate the static case, i.e. the car is not moving with its headlamps shining onto the measurement wall. In the dynamic case, however, when the car is driving on a bumpy and winding road, the headlamps' light moves over the landscape. In this case, a fast evaluation of the lighting characteristics as well as of the effects of changing control parameters when using AFS-headlight[1] is crucial.

Therefore, an interactive application like a driving simulation is needed to evaluate the headlamps' prototypes. However, due to the complex lighting dataset the computation of only one single view can take up to several hours [4]. Thus, raytracing techniques cannot be used with an interactive application.

2. Requirements and Design Goals

The automotive industry uses VR-technology for driving simulation within the development and evaluation of new car concepts. Mostly these systems visualize a car drive at daylight. A visualization of nightly scenes is often done by using conventional, OpenGL-based lighting effects. But standard OpenGL light sources offer just:

- A simple light model, i.e. a conic emission characteristic, which cannot emulate a headlight's complex luminance distribution
- No distance-dependent attenuation for the luminance
- No complex luminance distribution (see figure 3)

A further problem is a permanently changing position and orientation of the light source and the user's viewpoint within a nightdrive situation. Thus, it is not sufficient to calculate the illumination of the whole scene in advance, because the illumination conditions change drastically depending on the headlights' position and orientation.

In contrast to standard driving simulators a nightdrive simulator must provide a physically correct representation of the illuminated scene at night [5].

Therefore, Hella KG Hueck & Co. has developed the in-house nightdrive simulator *Nightdriver* [1], [2] that focuses on providing a physically correct representation of a headlight system's illumination at night. The system provides tools to analyse and evaluate the luminous characteristics of early headlight prototypes. *Nightdriver* visualises a headlight's luminance distribution into a virtual landscape in real-time (see figure 4). With *Nightdriver* the user drives on a virtual test track which simulates a real scenery. During the drive the luminance distribution of various headlight systems illuminating the virtual landscape can be examined. The system allows to simulate different illumination and traffic situations. The reproducible testing conditions of *Nightdriver* allow:

- to directly compare different headlight systems,
- to conduct psychological tests concerning traffic safety, and
- a significant reduction of real test drives at nighttime.

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[1] Advanced Front Lighting System: adaptive headlight system, which changes the headlight's direction due to the steering angle while driving through a curve.

Figure 4: *Nightdriver: Typical nightly situation with high beams illuminating a shack in a small village*

Hella's *Nightdriver* eliminates the above mentioned drawbacks of OpenGL-based lighting and provides a physically correct illumination. But the system highly depends on a specially adapted geometry model for the test track and its surrounding scenery. To ensure a correct lighting the test track's geometry model needs to consist of densely tessellated polygon meshes (see figure 5). The reason for this is that luminance data is mapped onto every vertex in the polygon mesh and luminance data is interpolated for every face in between the vertices [8], [9].

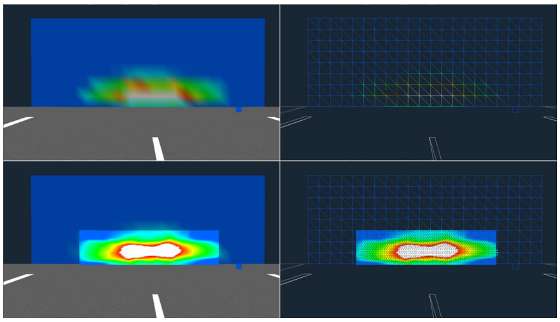

Figure 5: *Nightdriver: False-color luminance distribution on measurement wall with coarse (upper line) and dense polygonmeshes (lower line)*

This leads to a high polygon count and possible performance bottlenecks, especially when the scenery is getting more complex. In addition, any changes or updates to the test track and its surrounding scenery are a cumbersome and time-consuming task.

Therefore, our new concept for a real-time representation of lighting data has to meet the following requirements:

- No special preparation of the test track's geometry model, i.e. use of simple geometries avoiding complex polygon meshes but still ensuring a correct illumination when using complex luminance distributions
- Frame rate of at least 25 fps
- No special requirements on hardware: standard PC with hardware-accelerated graphics card, running under Windows2000
- Support of various types of user interaction: acceleration, breaking, and steering cause the luminance distribution to sweep over the landscape depending on the vehicle motion
- Input of a luminance distribution dataset (simulated or measured)
- Online changing of different luminance distributions and headlight systems

3. Concepts for a Real-Time Representation of Lighting Data

To meet these demands, we developed the following approach shown in figure 6. The basic idea is to use a homogenous emitting OpenGL light source as a slide projector. The luminance distribution functions as a slide being projected onto the landscape in the nocturnal scenery. The slide filters the homogenous OpenGL light source to provide the complex lighting characteristics.

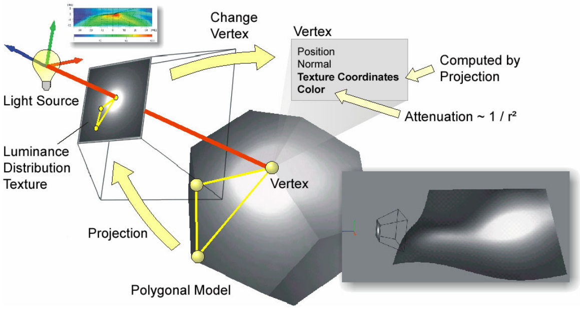

Figure 6: *Function principle for real-time representation of lighting data using a luminance texture as a slide*

To add the headlight's illumination onto the scenery the standard rendering pipeline is extended by some additional steps after an object has been transformed, textured, and ambiently lighted.

The steps contain roughly the following operations:

1. Project the vertices of a scene object by an inverse perspective transformation onto its corresponding point on the luminance distribution texture.

2. Determine the illumination intensity according to the point's position on the luminance distribution texture.

3. Calculate the final illumination of the scene objects by using a vertex shader. The vertex shader considers the illumination intensity value from step 2, the color of the corresponding ambient lighted object vertex, and the distance between the vertex and the observer for the distance-dependent attenuation of light.

4. Prototypic Implementation

To demonstrate the capability of our approach a prototypic application has been implemented (see figure 7 and figure 8). The application provides a simple test track to illustrate the effects of different lighting characteristics on the virtual landscape.

The user can switch between different luminance distributions to evaluate the resulting illumination effects. To verify the lighting characteristics a measurement wall in a standard distance of 10 meters as well as a false-color mode can be activated. Applying the vertex shader allows us to use just a very simple geometry model for the test track itself. This way, possible performance bottlenecks concerning the polygon count can be avoided while still showing fine details of the headlight's lighting characteristics on the illuminated scenery of the test track.

The implementation of the prototype was done using the software libraries OpenGL [7] and Alchemy 1.5 [6] from Intrinsic Graphics Inc. The virtual test track was created using Paradigm's 3D-modeller MultiGen.

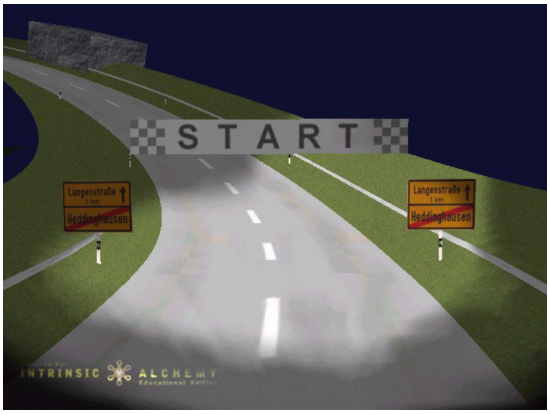

Figure 7: Prototypic implementation: light simulation in a nightdrive situation – front view

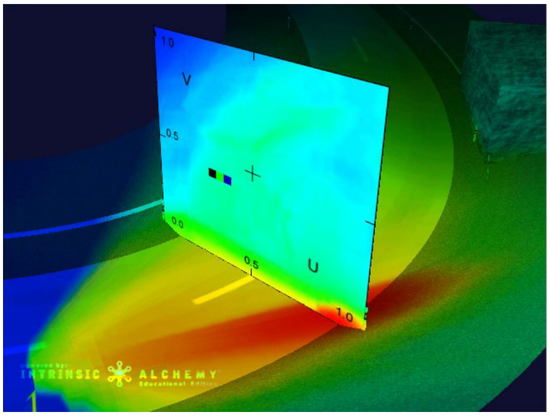

Figure 8: *Prototypic implementation: false-color representation of the headlight's luminance distribution on a measurement wall*

5. Evaluation and Performance

Using a vertex shader makes our approach independent from the way the geometry model of the scenery is divided into polygons. As the vertex shader projects every texel of the luminance texture onto the polygonal model of the illuminated object, the illumination quality does not depend on the subdivision of the objects' faces into small polygons. Figure 9 shows a measurement wall being illuminated in fine detail although the wall consists of only 2 triangles (see figure 10).

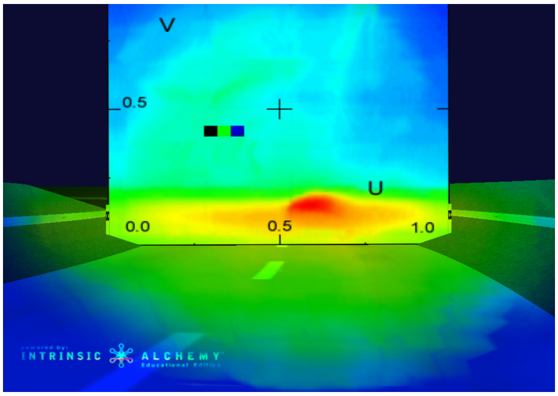

Figure 9: *Prototypic implementation: luminance distribution on measurement wall*

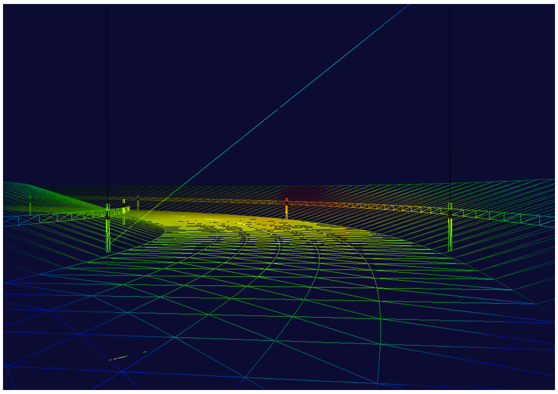

Figure 10: *Prototypic implementation: luminance distribution on measurement wall in wireframe-mode (note the wall just consists of 2 triangles)*

To obtain an illumination in such detail in Hella's *Nightdriver* the measurement wall needs to consist of many more polygons (compare with figure 5). Therefore, the density of the polygon mesh has no effect on the illumination quality which is projected onto the polygon model. A possible polygon count bottleneck is hence eliminated. The time-consuming task of creating an optimized model of the test track is no longer necessary.

The illumination quality of our approach rather strongly depends on the resolution of the texture being used for the luminance distribution. To obtain a sufficient lighting quality, even at greater distances between the headlamp and the illuminated scene, textures with a resolution of 1024 by 1024 pixels are used. As texture memory of current graphics cards is not a limiting factor anymore, there is no problem using even higher resolutions for the luminance distribution texture.

We built a virtual test track for Hella's Nightdriver emulating a real 5 mile test track Hella uses to evaluate physical prototypes of their new headlight systems (see figure 4). The virtual model contains about 1.5 million triangles. 80 percent of the triangles are used for dense polygon meshes building the objects of the scenery which are to be illuminated by the headlights. With our approach, we can reduce these polygon meshes completely by simply using one large face for each polygon mesh while still receiving the same lighting quality. That way, in case of the virtual test track we only need about 20 percent of the polygons for the same model and can utilize the polygon savings for more details in a future scenery. As the approach is currently not yet integrated into Hella's *Nightdriver* application we cannot compare the performance gain of our approach directly.

6. Summary and Outlook

In contrast to standard driving simulation software the developed concept for a real-time representation of lighting data allows the correct illumination of the whole scene without any adjustments of the illuminated scene. Nevertheless, the optical lighting characteristics are reproduced physically correct within the virtual environment.

The developed prototype is currently refined to be integrated into Hella's Nightdriver application. To better simulate the effect of the vehicle motion onto the headlights illuminating the nocturnal scenery, a multibody simulation is planned to be integrated. It is also planned to include the simulation of special weather conditions like fog or rain. This will probably also be done using the special features of current graphics hardware (i.e. vertex and pixel shaders). Simulated glare effects of oncoming traffic as well as variable traffic situations using parametrical models for the whole test drive scenery are also planned to be implemented.

Acknowledgements

The described prototype was implemented in cooperation with Hella KG Hueck & Co., Lippstadt, a German manufacturer for automobile lighting systems. We thank Dr. T. Weber from the computer aided lighting group for supporting us in the concept and design phases and providing us with the necessary illumination data of various headlights.

The application *Nightdriver* and the above mentioned work are subject to a research project within the L-LAB a public private partnership between Hella KG Hueck & Co. and the University of Paderborn, Germany.

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