A High Dynamic Range Rendering Pipeline for Interactive Applications

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Abstract

High Dynamic Range (HDR) rendering has a growing success in video-games and virtual reality applications, as it improves the image quality and the player's immersion feeling. In this paper, we propose a new method, based on a physical lighting model, to compute in real time a HDR illumination in virtual environments. Our method allows to re-use existing virtual environments as input, and computes HDR images in photometric units. Then, from these HDR images, displayable 8-bit images are rendered with a tone mapping operator and displayed on a standard display device. The HDR computation and the tone mapping are implemented in OpenSceneGraph with pixel shaders. The lighting model, together with a perceptual tone mapping, improve the perceptual realism of the rendered images at low cost. The method is illustrated with a practical application where the dynamic range of the virtual environment is a key rendering issue: night-time driving simulation. This work will be published on the CGI 2010 conference.

Keywords: Rendering, High Dynamic Range, Perceptual Realism, Interactivity.

1. Introduction

Immersion is a major goal for virtual reality applications. Among the factors which contribute to this objective, the perceptual realism of the displayed images is paramount. The most straightforward way to achieve perceptual realism is to get physical realism. However, reaching physical realism raises tough problems, both in terms of real-time computation and physical modelling. Next, one must collect the photometric and colorimetric data needed for the illumination computation. Then, the full simulation of the scene illumination in large virtual environments is far from real time. And finally, one cannot avoid the technical limits of current display devices, which are not designed to display physical High Dynamic Range (HDR) luminance values but Low Dynamic Range (LDR) 8-bit images.

Due to the limited luminance gamut of typical LDR display devices, one cannot avoid to loose physical realism somewhere along the rendering pipeline. Usual LCD display devices cannot render bright light sources (limit around 300cd/m²) or very dark areas (lower than 1cd/m²). In contrast, the sensitivity of the human photoreceptors ranges between 10^{-6}cd/m² for starlight and 10^{8}cd/m² for sunlight. Thus, the HDR input range of the physical visual signal must be mapped to the dynamic range of the LDR display device, using a tone mapping operator keeping perceptual realism.

To address the issue of perceptual realism for interactive applications, we propose a two-step approach, summarized in Fig. 1. A real-time model of illumination leads to an intermediate HDR physical representation of the images to be displayed, in photometric units, thanks to a photometric description of the light sources and of the surfaces. Then, a glare simulation [2] followed by a tone mapping operator [1] transform the physically realistic HDR images into perceptually realistic LDR images on the fly. To our sense, our main contribution is that any existing virtual environment may be rendered with this pipeline, with only a few modifications of the environment, and a true improvement of the perceptual realism.

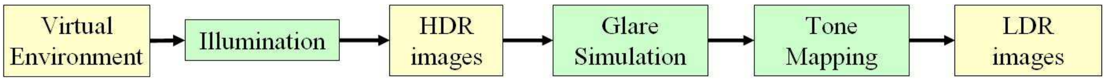

Figure 1: Proposed approach: a physically-based HDR rendering is followed by a perceptual tone mapping.

2. Framework

In the following, we propose a pipeline for the rendering of HDR virtual environments on conventional display devices (Fig. 2 [5]). The proposed framework includes 3 steps (the first one is offline):

- Pre-processing of an existing LDR virtual environment, providing a HDR photometric description of the light sources.
- HDR rendering of the virtual environment using a physically based rendering model (see left of Fig. 2).
- Post-processing of the HDR images (glare and tone mapping), to compute displayable LDR images with perceptual attributes as close as possible to those in the HDR image (right of Fig. 2).

a. HDR light sources

Depending on the available virtual environment, the light sources must be modified or added. For the illumination model, the intensity and the shape of the light sources are given in photometric and goniometric units, taken from lighting designers and lighting databases. For the direct illumination (when the light source is in the field of view), the light source texture is converted from a LDR to a HDR texture image, (or to an `Emissive` Material, see the *OR* box in Fig. 2) according to photometric data.

b. The HDR lighting model

The virtual environments include texture information and materials description. Our hypothesis is that the final tuning of the textures was set in order to get the right visual appearance of any surface, on a screen with a given γ ($\gamma = 2.2$ in the following). Thus we converted the texture images T into dimensionless reflectance maps ρ:

$$\rho = T^{\gamma}$$

This trick enables to re-use existing LDR virtual environments with a physical lighting model, using the HDR light sources described in photometric units.

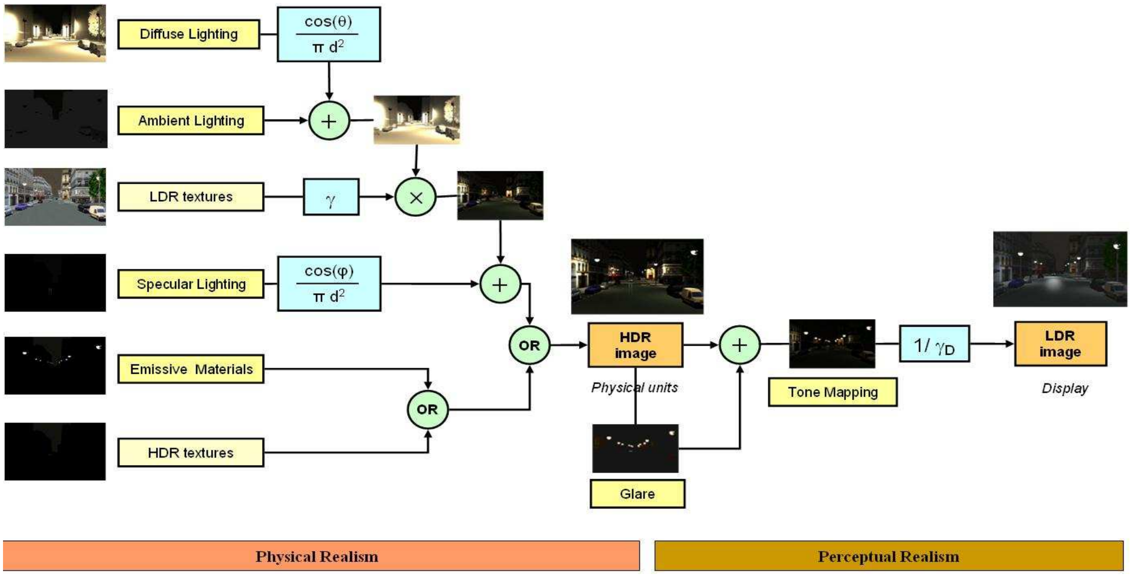

Figure 2: HDR rendering pipeline for virtual environments based on a physical lighting model and a perceptual tone-mapping.

Then, as in Phong's model, the luminance L is split in 3 parts: $L = L_A + L_D + L_S$ (`Ambient`, `Diffuse` and `Specular` [3,6]). In the following, I is the intensity of the light source, M the material, and the ρ reflectance map from Eq. 1, d is the distance between the light source and the surface, $\cos\theta$ the angle between the incident light and the normal, and $\cos\varphi$ the angle between the reflection vector and the eye. The HDR `Ambient` term L_A provides an illumination to everything in the scene, the `Diffuse` luminance L_D models light reflections equally scattered in all directions, and the `Specular` luminance L_S models the reflections on mirror-like surfaces:

$$L_A = \rho I_A M_A \qquad L_D = \frac{\rho I_D M_D \cos\theta}{\pi d^2} \qquad L_S = \frac{\rho I_S M_S cos\alpha^{sh}}{\pi d^2}$$

c. Tone Mapping

A number of tone mapping operators have been proposed. For our two-step approach (Fig. 1), we needed a tone mapping operator which secures key perceptual attributes in the images. Thus, we adapted Irawan et al.'s algorithm [1], which is derived from the Histogram Adjustment method proposed by Ward et al. [7], and also takes into account the temporal adaptation of the human visual system with a psychophysical model derived from Pattanaik et al. [4]. This operator was designed to keep perceptual realism in terms of visual performance and temporal adaptation, so we could take advantage of the physical illumination model in the virtual environment.

3. Results

Fig. 3 shows screenshots, as well as a view of the original LDR environment. The *Rivoli* Environment, including 75 light sources, runs at 30 frames per second, with 1680x1050 images on a Intel Core2 Duo, with a nVidia GeForce GTX 280 GPU. The graphic pipeline is implemented in *OpenSceneGraph* with pixel shaders.

One practical advantage of the proposed technique is that one can easily re-use such an existing LDR environment, for instance for video games and driving simulators applications.

Figure 3: Screenshots of the HDR night-time rendering of the *Rivoli* virtual environment. Top left: original LDR environment used as input.

4. Conclusion

We propose a HDR rendering pipeline for interactive applications, focusing on the perceptual realism of virtual environments. The pipeline was demonstrated in a city street environment at night, with only small changes in the environment description. The HDR environment is then rendered using a photometric model of illumination allowing us to include dozens of light sources. The resulting HDR images are processed by a glare simulator and a perceptual tone mapping operator.

As the aim of the proposed rendering pipeline was perceptual realism, an important issue is to assess the visual quality of the displayed images. This may be done by comparing the displayed images with various state of the art tone mapping operators, with subjective and/or objective criteria.

References

[1] Irawan, P., Ferwerda, J.A., Marschner, S.R.: Perceptually based tone mapping of high dynamic range image streams. In: Proceedings of Eurographics Symposium on Rendering (2005)

[2] Kawase, M.: Practical implementation of high dynamic range rendering. In: Game Developers Conference (2004)

[3] Mitchell, J., McTaggart, G., Green, C.: Shading in valve's source engine. In: Proceedings of SIGGRAPH, pp. 129–142. ACM (2006)

[4] Pattanaik, S.N., Tumblin, J., Yee, H., Greenberg, D.P.: Timedependent visual adaptation for fast realistic image display.In: Proceedings of SIGGRAPH, pp. 47–54. ACM (2000)

[5] Petit, J., Brémond, R.: Interactive high dynamic range rendering for virtual reality applications. In: Proceedings of Virtual Reality and Software Technology, pp. 251–252. ACM, Kyoto (Japon) (2009). (poster abstract)

[6] Phong, T.B.: Illumination for computer generated pictures. Communication to the ACM 18(6), 311–317 (1975)
[7] Ward, G., Rushmeier, H., Piatko, C.: A visibility matching tone reproduction operator for high dynamic range scenes. IEEE Transactions on Visualization and Computer Graphics 3(4), (1997)