Workshop on Material Appearance Modeling (2018)
H. Rushmeier and R. Klein (Editors)

Iso Photographic Rendering

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Abstract

In the field of computer graphics, the simulation of the visual appearance of materials requires an accurate computation of the light transport equation. Consequently, material models need to take into account various factors which may influence the spectral radiance perceived by the human eye. Though numerous relevant studies on the reflectance properties of materials have been conducted to date, environment maps used to simulate visual behaviors remain chiefly trichromatic. Whereas questions regarding the accurate characterization of natural lighting have been raised for some time, there are still no real sky environment maps that include both spectral radiance and polarization data. Under these conditions the simulations carried out are approximate and therefore insufficient for the industrial world where investment-sensitive decisions are often made based on these very calculations.

Categories and Subject Descriptors (according to ACM CCS): I.3.1 [Computer Graphics]: Hardware Architecture—Input devices I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Raytracing I.6.8 [Simulation and Modeling]: Types of Simulation—Visual J.2 [Computer Applications]: Physical Sciences and Engineering—Engineering

1. Introduction

In our daily life, but also in the academic and industrial worlds, computer graphics and in particular synthetic imaging are more and more present. These digital creations provide users and consumers with representations of a "reality" invented, disappeared or coming in the form of credible or plausible visual illustrations. Computer graphics are used in activities where visual restitution and/or aesthetic judgment are crucial.

The effectiveness of current tools used to generate computer graphics is well-established - the prevalence of special effects alone in cinema, advertising, and video games serves as ample proof. When these images are used for entertainment, or any public setting, we like to call them **photo-realistic** imagery; and in these situations, a great deal of importance is given to a creator's talent and artistic interpretation. In an industrial setting, however, this freedom of interpretation comes at the cost of credibility and reproducibility. Here, decisions are based more on whether to accept or reject a given proposal, rather than on which artistic solution to highlight; and as a result, synthetic imaging as a simulation tool must be both reliable and objective. Still, in light of our experience, we believe that too few decisions are being made on the basis of computer-generated images. Synthetic imaging can actively reduce costs by limiting the number of physical prototypes, while allowing the multiplication of virtual tests. Likewise, in the academic world computer-generated images are as illustrative as value tables, curves, and graphs. They are a visual, faithful and predictive representation of the results obtained from the studied phenomenon. And finally, it goes without saying that repeatability is imperative in the scientific process. These two principles, repeatability and predictivity, distinguish this form of synthetic imaging from the previous one; they are, in our opinion, the keys to **physico-realistic** imagery.

2. Previous work

A great deal of work has been done in this field of computer-generated imagery, and in this short article it would be irrelevant to provide an exhaustive list. In the book: "Digital Modeling of Material Appearance" [DRS08], a (predictably) interesting and comprehensive study of the digital modeling of material appearance is made, yet the authors mention "digital models of appearence to give viewers a credible visual impression of the depicted materials". Naturally, this statement is inconsistent with the context of industrial decision-making; [WWMC09] offers the elements needed to achieve the level of predictive rendering that is essential for a trusted use by industrialists in the design phase.

In 1999, in the article: A framework for Realistic Image Synthesis, [GRE99] wrote: "Our goal is to develop physically-based lighting models and perceptually-based rendering procedures for

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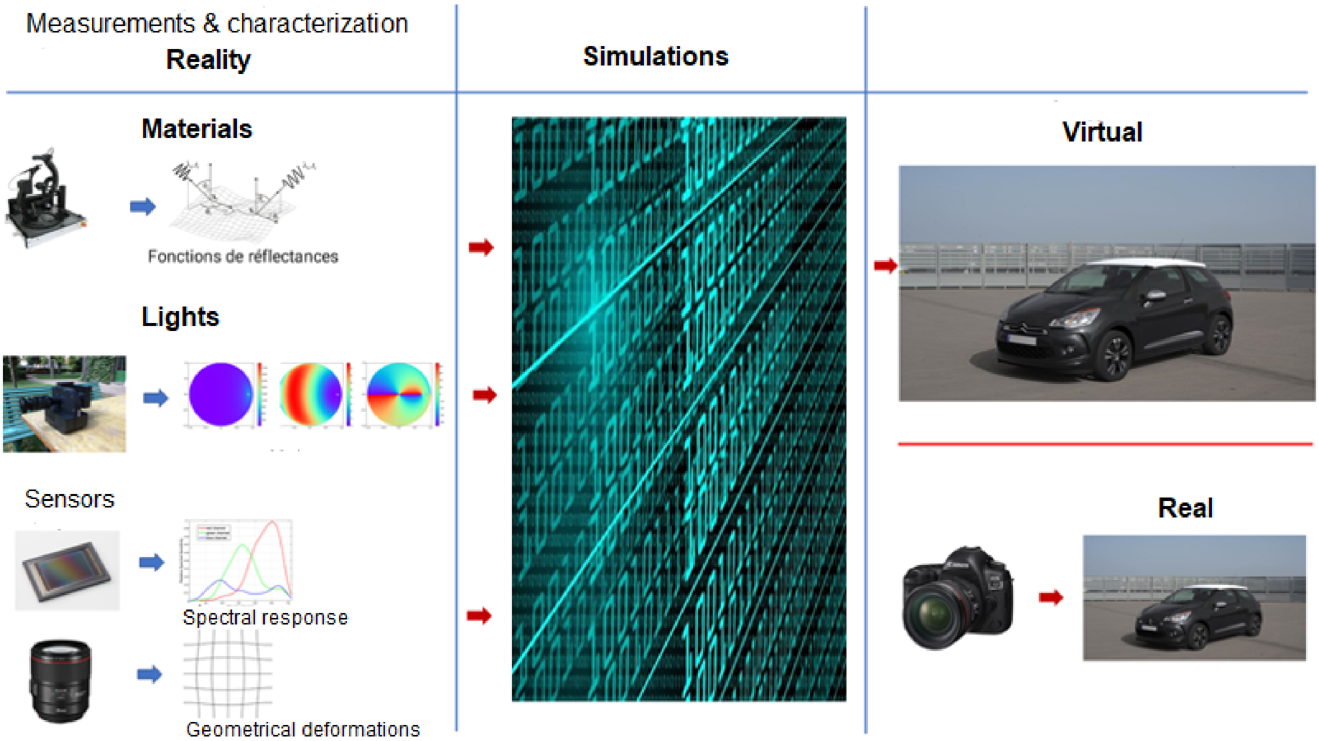

Figure 1: *Individual components to achieve iso photographic rendering.*

computer graphics that will produce synthetic images that are visually and measurably indistinguishable from real-world image". In order to achieve this goal, the authors propose three lines of research:

1. Fidelity of local models of light/matter interaction;
2. Exact energy transport simulations;
3. Visual restitution algorithms.

To date, none of these conditions have been entirely fulfilled by synthetic imaging solutions (synthetic image creation solutions), whether on a commercial or academic level. In general, simulating the visual restitution of a scene requires taking into account all elements that can have an influence on the energy spectral luminance received by a human eye. Thanks to a great deal of academic work, along with the current performance of processors, graphics cards, and programming techniques, the simulation of energy transport is no longer a significant problem. The simplifications that were historically necessary to ensure rapid and efficient calculations can now be lifted. On the other hand, ensuring that modeled lights and materials are perfectly representative of the real world remains fundamental.

3. Proposition

It is essential for manufacturers to gain confidence in such tools; and we're hoping to earn their trust by showing them 'photographs' of objects before they even exist. Photography involves capturing reality at any given moment, and the only bias it introduces is related to the camera itself: optics, sensors, and electronics. Under these conditions, if we know the intrinsic characteristics (BSDF) of relevant materials measured in the laboratory, possess a complete acquisition (spectral and polarized) of light in the moment the picture was taken, and know the characteristics of the camera, it should be possible to recreate a virtual image identical to what the 'real' photograph would have looked like (see fig. 1). In this process, as only measured data is used to feed the rendering engine, an inherent link is established between the real and virtual images. And since all measurements are made from real samples, industrial feasibility is assured - something that isn't always the case with analytical models. The relevance of this method is twofold. First of all, if the raw writing format of the calculated virtual image is the same as the one recorded by the camera, and the same electronic processing can be applied, then it will be possible to display both images side by side, free of any bias generated by the screen (gamut, calorimetric calibration...). Second, as the measurements are made on real samples the feasibility of manufacturing is ensured. In these conditions, the two images become perceptively indiscriminable by an observer, fulfilling the criteria proposed by Greenberg et al. From there, convincing manufacturers of this solution's predictivity should be a simple matter.

The fidelity of local models of light/matter interaction is at the center of this debate. The reflectance properties of materials have a predominant impact on it, but other significant properties of light, such as its spectral distribution and polarization, must be included to achieve physically correct results. These properties of materials and light constitute input information necessary for a rigorous resolution of the light transport equation.

3.1. Scalar light transport vs Vector light transport

The rendering engine must necessarily take into consideration all the laws of physics. The light transport must not only deal with the spectral intensity in scalar form. The calculations must be done in vectorial mode, i.e. in propagation of a Stokes vector (I, Q, U, V) associated with the Muller matrix formulation. The figure 2 presents, in an extreme case, the inaccuracy of a rendering in a scalar use.

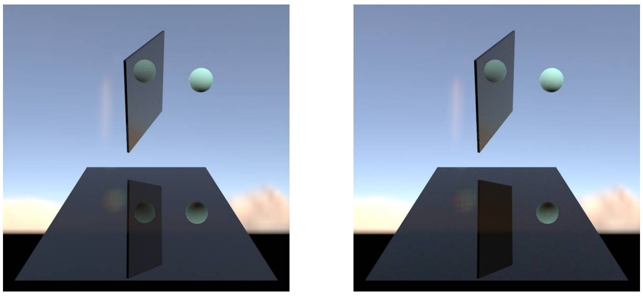

Figure 2: *Simple geometry at Brewster's angles. left : computation without polarization, right : with polarization. In this case, the second reflection of the sphere is no longer present.*

3.2. Measurered BSDF

There are several devices on the market for measuring reflectance functions (BSDF), and they can be divided into two categories: goniometric and optical. Taking into account only devices allowing acquisition in spectral mode, both categories have advantages and disadvantages. Goniometric devices are very slow to use when the number of illumination directions is high; moreover, measurements are made only in the plane of incidence, excluding the anisotropic behavior of materials. Optical devices are much faster to use and acquisition is not limited to a plane of incidence, but they lose accuracy due to the limited dynamics and noise generation of CCD and CMOS sensors. Generally, it should be noted that the effects of polarization are not taken into account. In some cases (for metals or dielectrics), the measurements of the optical complex constants are carried out by ellipsometry, and the Fresnel laws remain applicable. In any case, industrial companies will usually possess their own devices, have measures tailored to their needs. Exploiting their own data creates a great deal of confidence in the results of the simulation.

3.3. Measured or simulated environment light

When all material-related information is known, the only remaining variables concern the acquisition of luminous environments, while taking into account the totality of the laws of physics (intensity, spectral distribution, polarization). Obviously, a rigorous characterization of the light source is an essential component, and we find that today there is no relevant and exploitable environment map taking into account all the physical characteristics necessary for a predictive simulation. Only a few parametric environment models (which we consider too simplistic) or trichromatic acquisitions are available. It is important that new solutions be proposed for modeling and/or capturing natural light. [Por16]] proposes new solutions of modeling and/or capture, exploiting results from other scientific fields, such as meteorology, climatology, or remote sensing to generate a model of a clear, cloudless sky. Figure 3 displays the result of one such simulation.

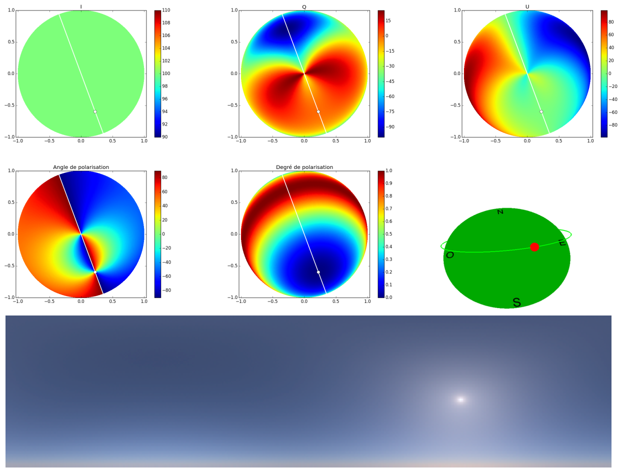

Figure 3: *First row, from left to right: components of the Stokes vector I, Q, and U. Second row, from left to right: angle and degree of polarization. Paris (France), 1 A.M., August 25, 2017. Azimutal angle:* 159.559°. *Elevation Angle:* 50.4092°, *Azimuthal Angle:* 159.559°

Since all situations cannot be realistically addressed by this method, a device has been developed for the acquisition of generalized lighting environments, incorporating the dynamic range of lighting, its spectral distribution and its polarization states. Figure 4 presents this device and its principles.

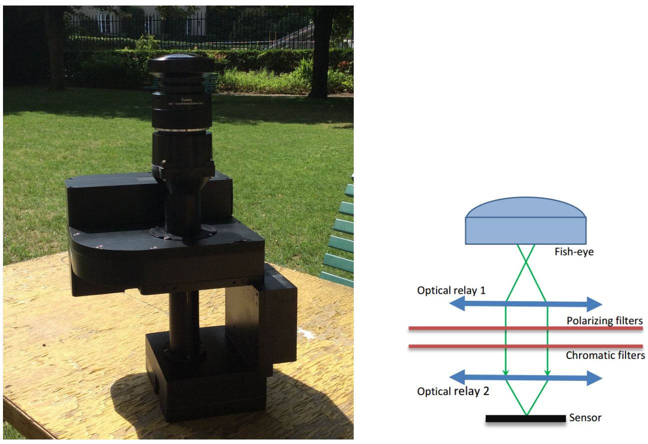

Figure 4: *Device and principle proposed by [Por16]*

This system is based on the sequential acquisition of images successively filtered by chromatic and polarizing filters with different exposure times (equivalent in principle to an HDRI capture). Although fully operational, this device remains limited by the total time of capturing. A major evolution based on a new original sensor is planned in order to optimize the acquisition time.

3.4. Interactive visualization

In reality, to correctly evaluate the appearance of a material in a precise luminous environment, the observer moves around the object to observe its various properties (reflections, specularity, brilliance). As a consequence, dynamic observation is a requirement when assessing the visual appearance of a virtual product.

Despite tremendous research efforts, convergence rates of modern unbiased light transport algorithms are still insufficient to achieve a seamless perceptual experience. As an alternative, leveraging the power of modern supercomputers readily available in high-end industries seems to be a natural way to significantly reduce image computing times.

Many efforts targeting efficiently distributed rendering have been carried out in the last decades [CRD02, TS16, RCD*18]. However, it is important to note that real-time predictive visualization remains out of reach, even with cutting-edge hard ware combine with state-of-the-art distributing approaches.

4. Conclusion

In the industrial world, especially in creative design, simulation methods and tools have been successfully completed and are used routinely. In industrial design, however, where feasibility of manufacturing must be established, current tools remain insufficient. Today, the individual elements necessary to bring simulation to a satisfactorily predictive level have been identified, and are available. But in order to offer complete and efficient tools, a special effort must be made for their integration. Note that in more complex areas (cosmetics, organic textures, ...) there is still much research left to be done, notably for BSSRDF and BTF.

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