UTILIZATION OF IMAGE TECHNOLOGY IN VIRTUAL LIGHTING LABORATORY

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ABSTRACT

Lighting can be better integrated to the architectural design process through computational tools that are capable enough to visualize and analyze the luminous environment accurately. This paper describes an image-based lighting analysis procedure that operates with high dynamic range lighting data for evaluating architectural spaces. The discussions mainly refer to visual and metrological aspects of digital image processing with reference to their applications in architectural lighting design and analysis.

Keywords: lighting analysis, digital image processing, high dynamic range (HDR) imaging

1. INTRODUCTION

The lighting accuracy of digital images depends on the input and algorithmic capabilities of the rendering software. Given that, computational accuracy does not necessarily produce a visual match of the real-world scene. Display medium limits the luminance range and colour gamut of the image [1]. Therefore, it might be erroneous to make lighting design decisions and performance evaluation from the appearance of the displayed images. However, the numerical data embedded in digital images can be invaluable for advanced lighting analysis [2].

2. IMAGE ANALYSIS GUIDELINESS FOR ARCHITECTURAL LIGHTING RESEARCH

There are certain image criteria in order to achieve meaningful photometric information from digital images. The image analysis guidelines for architectural lighting analysis are listed here as the requirement for high dynamic range data and compliant image format, conversion between RGB and CIE XYZ, exposure adjustment, gamma correction, and appropriate projection and viewpoint selection.

2.1 Requirement for high dynamic range data and compliant image format

The dynamic range of luminance values encountered in architectural spaces can be vast. The variation from starlight to sunlight is 14 logarithmic units [1]. Physically based rendering tools generate images with High Dynamic Range (HDR) pixel values. Floating-point colour representations (RGB) are used internally, but the display and storage of this data is not feasible. For storage, the data is usually clipped into 24 bit/pixel integer values, which allows a dynamic range of about 2 logarithmic units. This solution is efficient in terms of disk space, but the lost information is irrecoverable in terms of extracting absolute photometric information, performing operations outside the dynamic range of the stored values, and readjusting the exposure.

For lighting analysis purposes, it is necessary to keep the original quantities with an adequate image format. RGBE image format maintains floating point data with a 32 bit encoding such that 8 bit mantissa allocated for each primary (RGB) share a common 8 bit exponent. It can store a dynamic range of 76 logarithmic units [3]. SGI Logluv format covers a range of 38 logarithmic units [4]. Therefore, these two image formats enable the storage of HDR lighting data.

2.2 Conversion between RGB and CIE XYZ

RGB is often used as the basis of color space and color computation in computer graphics. The rendering software internally defines the CIE chromaticity coordinates of the RGB values [5]. Photometric data can be generated from HDR images through a series of calculations that involve conversion from RGB to CIE XYZ values for each pixel.

2.3 Exposure

Low dynamic range image formats store lighting intensity similar to the range of conventional electronic and print-based media. However, HDR images have dynamic lighting variation that is much wider than the display media. The data may be clipped or compressed through tone mapping operators. If these operations alter the pixel values, the alteration should be reversed before CIE XYZ conversion. Another solution is to adjust the exposure to optimize the visibility of different areas of the scene over the wide range. Exposure value is a linear scaling factor applied to pixel values to map the computed luminance to the appropriate display range [6]. Exposure value is needed to compute the absolute CIE XYZ values.

2.4 Gamma correction

Color computation is based on linear intensity values. However, display devices like CRT's cannot produce a light intensity that is linearly proportional to the input voltage. Gamma correction is the process of balancing the nonlinearity of the display device. Gamma correction is either stored in the image file; or executed at the time of the display. The first technique assumes a certain gamma value and alters the pixel values accordingly [5]. Again, this operation has to be reversed before CIE XYZ conversion.

2.5 Projection and viewpoint

The exact position of the occupant is important for lighting analysis, since the focus is mostly on the amount of light reaching the eye. It is useful to generate hemispherical fisheye images from the view of the occupant. A hemispherical fisheye is a half sphere projected such that each differential area corresponds to the original area multiplied by the cosine of polar angle. Illuminance is equal to the product of π with the uniform sampling of luminance over the projected hemisphere [6]. Hemispherical fisheye projections cover the total human vision with view angles that can be as wide as 180° vertically and horizontally.

3. VIRTUAL LIGHTING LABORATORY

Through the application of the techniques listed in Section 2, HDR images can be utilized as lighting laboratory settings. Virtual Lighting Laboratory (VLL) is a computer environment, where the user has been provided with matrixes of illuminance and luminance values extracted from images (Figure 1). The underlying idea is to provide the 'laboratory' to the designer / researcher to explore various lighting analysis techniques instead of imposing limited number of predetermined metrics.

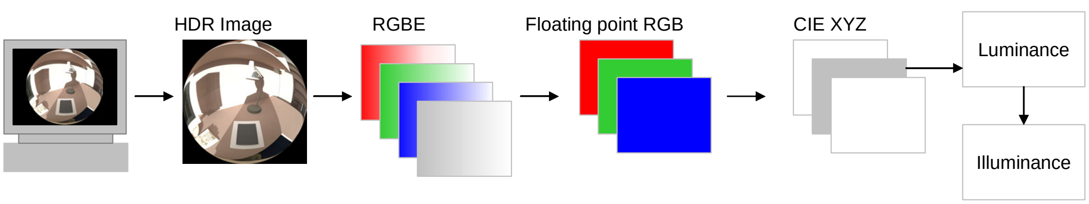

Figure 1 Image analysis sequence in VLL.

3.1 Image Properties

The images utilized in this paper are generated with Radiance software, which provides HDR pixel values that correspond to the physical quantity of radiance. The RGB color space is computed from the radiance value in three channels as floating point numbers and stored in RGBE format. RGB value of (1,1,1) is equal to a total energy of 1 watt/steradian/m^2 over the visible spectrum [6]. Therefore, it is possible to post-process RGBE images to retrieve lighting information.

3.2 Lighting Analysis

Mathematical operations and statistical analysis can be performed with the computed quantities. Per-pixel lighting data is invaluable information for analysis, but it might also be an extensive amount of knowledge to process. The rest of the paper provides a general span of the architectural lighting analysis capabilities and procedures within the VLL.

3.2.1 Per-Pixel Lighting Analysis

Computed quantities can be utilized in various luminous environment indicators such as illuminance and luminance distribution, luminance contrast, glare indices, contrast sensitivity, visual acuity, and visibility on threshold and supra-threshold lighting levels. The example shown is an office space (Figure 2). The first three images are generated from occupant's point of view while performing typical visual tasks. They are used to study the characteristics of light that reach the eye. The next two images (pc-view and paper-view) demonstrate the volume seen by the illuminance meter, if physical measurements were to be taken. They are used to study the characteristics of light that fall on the tasks.

In lighting practice, it is common to compare luminance ratios on task and certain architectural elements such as wall, ceiling, surround and etc [7, 8]. Therefore, the scene is decomposed into elements. The computer screen and paper has two parts; black and white representing the text and background, respectively. The other elements identified in this image are the wall behind the task, table, and the window. Minimum, maximum, and mean luminance values, luminance range and ratios are identified. Luminance contrast is calculated for the paper and screen. The pixel information allows detailed study of the temporal and spatial dynamics within an environment, where lighting variability can be investigated and correlations can be established among different architectural surfaces. As an extension of the study, the scene is dissected into the specific regions of the visual field, i.e. foveal, binocular, and peripheral vision.

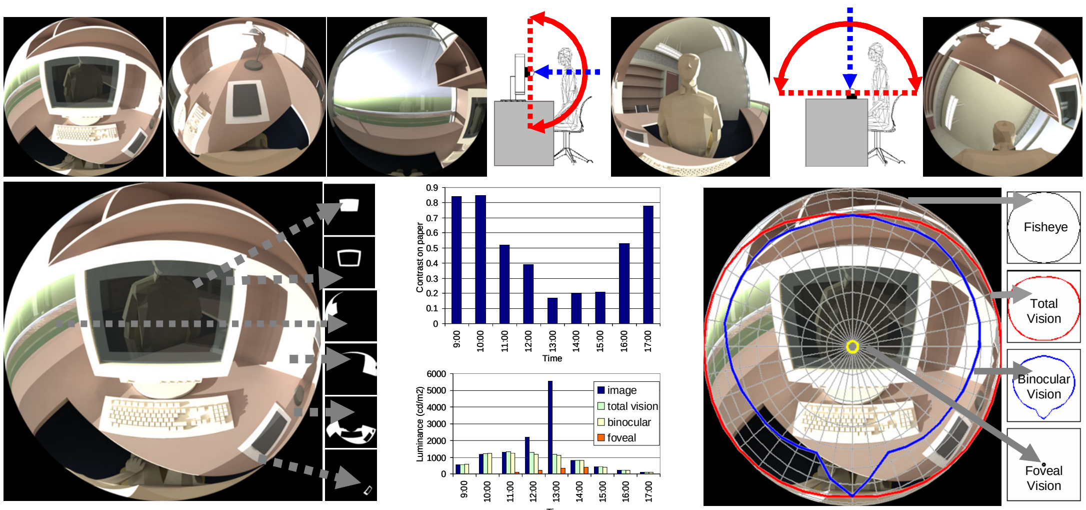

Figure 2 Per-pixel and regional lighting analysis: luminance variation within the space / visual field

3.2.2 Virtual Meters

Virtual meters can be built within VLL for conducting complex lighting analysis. They are very useful research tools as long as the researcher understands the capabilities, restrictions, and assumptions of the underlying algorithms. The examples given here are B&K contrast meter and an integrating sphere.

Contrast Rendering Factor (CRF) is an index of the effects of veiling reflections in reducing task contrast [7]. The virtual B&K contrast meter mimics the physical one: It consists of black and white surfaces, representing task and background. The entire surface is coated with a glass layer to allow specular reflections. CRF is calculated by comparing the contrast in the setting with the contrast in a reference environment. Figure 3 illustrate the veiling reflections from occupant's point of view. In Figure 3.a, the glass layer is totally washed by the light so it is not possible to see the black and white circles under the glass. If the task was a glossy magazine, we would not be able to read the text. In Figure 3.b, there is some veiling reflection. Visibility is totally restored in Figure 3.c.

The second example is an integrating sphere. Integrating sphere is simulated in VLL as a reference environment for CRF calculations. It is a hollow sphere enveloped with perfectly diffuse material to create uniform lighting conditions.

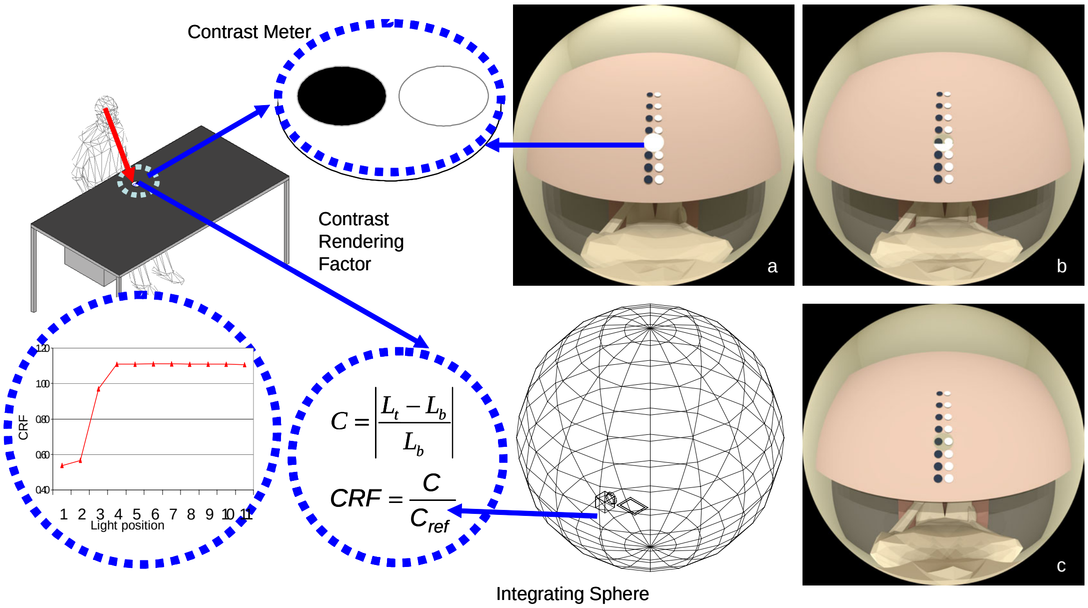

Figure 3 Virtual lighting meters: contrast meter and integrating sphere

4. CONCLUDING REMARKS

This paper introduces an image-based lighting analysis tool. Image analysis guidelines have been listed. It is hoped to assist lighting designers, specialized architects, and consultants with a tool / procedure that endorses lighting studies through per-pixel data analysis. In general, it provides numerical and visual means for better integration of lighting analysis and design process.

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