Technical Review

The Use of Luminance Mapping in Developing Discomfort Glare Research

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Received December 16, 2009, Accepted February 18, 2010
This paper was presented at the 6th Lux Pacifica, Bangkok, Thailand, April, 2009

ABSTRACT

Daylighting offers environmental, economic and social benefits when applied successfully; however, poor use of daylight causes unwanted heat and glare problems that negate the desired benefits. In order to develop effective daylighting practices, a reliable method for assessing discomfort glare for occupants is required. The aim of this study was to capture the luminance distribution within a daylit scene and use this information to quantify some of the physical parameters of glare. Computational tools were developed that use luminance data from corrected High Dynamic Range (HDR) images captured via a digital camera. These tools then calculate the physical parameters used in glare assessment. The discussed procedures allow for future research into discomfort glare to be informed by real situations, documented by lighting researchers and practitioners. With these tools a better understanding of discomfort glare can be established.

KEYWORDS: discomfort glare, luminance mapping, digital cameras, interior lighting

1. Introduction

An intelligent lighting design will increase occupant satisfaction while reducing operating costs and environmental pollution. It is essential that daylight effects are given due consideration in any space where daylight is admitted, even if it is not exploited as a light source, so that uncomfortable or distracting glare is minimised. This involves knowing the location of the user, the angles of view and the distribution of light on the room surfaces, as well as familiarity with specific lighting products. There are many different systems that have been produced for predicting the magnitude of discomfort glare; so far however, the precision and repeatability with which they predict an individual’s sense of discomfort is low\(^{12}\). Consequently these formulae have had limited success when used in lighting assessment.

There have been two main obstacles preventing the progression of discomfort glare research. Firstly, discomfort glare is subjective. Today it is widely accepted that glare associated with electric sources is different (in people’s sensitivity and method of perception) from glare associated with daylight. It is also widely accepted that the perception of glare in contrived laboratory environments is completely different from field situations where there are real tasks to perform and interesting visual background stimuli\(^9\). The second major obstacle in quantifying discomfort glare is the difficulty in analysing complex lighting distributions. Previously, experiments could only be designed to explore only the most basic lighting setups as researchers did not have effective tools to analyse complex variations of luminance within a large field of view. Subsequently, the results of research conducted in these contrived laboratory experiments were unable to predict glare when applied to people in real work environments.

Fortunately the advent of CCD cameras and various digital imaging techniques (such as High Dynamic Range (HDR) imaging) has helped to solve the latter difficulty in researching discomfort glare. The luminance distribution of any environment to be captured using only a digital camera fitted with a fisheye lens and the right software\(^4\). A CCD camera can also achieve this, but they are more expensive and require product specific software. The ability of digital images to be rendered into luminance maps quickly and accurately\(^9\) has made it an attractive technique for lighting researchers in analysing discomfort glare.

2. Discomfort glare research

Discomfort glare can originate from both natural and electric sources. It is a sensation of annoyance or pain caused by non-uniform distributions of brightness in the field of view that are significantly higher than the luminance to which the visual system is adapted\(^9\). Most assessments on the magnitude of discomfort glare are based on five physical parameters: Luminance of glare...
source, apparent size of glare source (solid angle), location of glare source within the field of view (vision axis), the number of glare sources and background luminance. For a complex lighting distribution the most effective way to determine these five parameters is via a luminance map.

Luminance mapping is not a substitute for physical measurements since it cannot be as accurate as physical measurements, yet it provides a way of collecting high resolution luminance data within a large field of view quickly and efficiently. High quality luminance maps can be created from real scenes using conventional camera equipment. A digital camera is essentially an imperfect device for measuring the radiance distribution of a scene, in that it cannot capture the full spectral content and dynamic range. The information is there, but limitations in sensor design prevent cameras from capturing all of it in a single exposure. Thus luminance mapping and HDR techniques require multiple exposure images of the same scene. Therefore a standard camera with the right software and photometric corrections can create a single HDR image from which accurate luminance data can be extracted.

To obtain valuable information on people’s perception of lighting environments it is important to obtain luminance information from a field of view at least as large as a person’s visual field of view. In order to achieve this, a fisheye lens is required. There are two types of fisheye lenses, equidistant and the less common orthographic projection (Figure 1). The equidistant projection method resolves the image onto the charged coupled device (CCD) so that the light beam angle of incidence is proportional to the distance from the image centre.

Recently, attempts have been made to analyse luminance maps of lighting scenes to produce indicators to predict the sensation of discomfort glare. Schiller analysed pixel histograms of conventional digital images taken in a real office environment. Osterhaus extended the work of Schiller by instead using luminance histograms of HDR images created with RADIANCE where four combinations of two parameters (mean pixel value and median pixel) were used to look for correlations with subjective data from a previous study. The most extensive study of glare using luminance mapping technology was in the development of the Daylight Glare Probability Index (DGP). The study used expensive CCD cameras to capture the luminance distribution of an office mock-up. These images were analysed using radiance’s evalglare function to find possible glare sources. This data was then used with subjective assessments to develop the DGP index.

3. Tools for discomfort glare

Though user assessments were not the focus of this study, luminance maps of situations where daylight glare would be present were required to test the computational tools developed. Several field images were obtained at a typical Brisbane CBD office. The images were taken late in the afternoon at approximately 4 p.m. in a west facing room where there were obvious glare problems. Two situations (Figure 2) are presented here as test cases for the computational techniques.

![Figure 2 - A typical office; View 1 - Blinds open (left), View 2 – Blinds Partially closed (right)](image)

In conducting glare analysis on images it is important to consider the occupants perception of the lighting environment. Thus an occupant who is assessing their lighting environment should be able to indicate to the lighting researcher what glare sources they observe, and give a categorical indication of the magnitude of the glare source. To help an occupant easily indicate their line of sight and what glare sources they observe in their field of view, an angular mesh was created as an overlay onto an image (Figure 3). The mesh defines sectors from tilt angles in steps of 30° from 0° to 360° and azimuthal angles in steps of 15° from 0° to 90°.

The first physical parameter that is required for

\[ \% \text{Outer} \text{Pix} = 100 \left(1 - \frac{\pi r^2}{2r^2}\right) = 21.5\% \]
evaluation of glare is the background luminance. In calculating the background luminance of a scene any pixels that are outside the fisheye boundaries should not be included. The percentage of pixels outside the fisheye boundary is given by;

Thus the lowest 21.5% of pixels aren’t included in the background calculation. A histogram of log luminance (Figure 4) shows the distribution of log luminances within View 1 (Figure 2).

The bars to the far left in the figure correspond to pixels that are outside the fisheye boundaries. In glare calculations, glare sources are not considered to be a part of the background luminance, thus glare pixels in an image must be excluded from the calculation of background luminance. The histogram is used to estimate how much glare is within the scene. A pixel was considered glare if it was 100 times greater than the background luminance. The described method will most likely work best for small area glare sources, such as the ones that will be presented in this study. If the histogram in Figure 4 had showed large peaks to the right, the scene would have contained a large area glare source which is more difficult to treat. In this case adaptation of the eye takes greater consideration. An idea would be to use a “task-zone” and calculate the background as the average luminance within that zone. Conversely an illuminance meter could be used to assess the adaptation level and use this to help work out a suitable background.

The visual system can function over about five orders of magnitude within a single scene\(^7\). Assuming that the background luminance represents the average luminance to which the eye is adapted, a pixel was determined to be glare if it was approximately 2 orders of magnitude above the background luminance. However, the advantage of having the lighting distribution of scene captured in a digital format is that it is possible to experiment with values. Figures 5 and 6 show an intensity plot of log luminances for both field images and the detected glare pixels.

Figure 5 shows why user evaluations of a scene are required, because knowing how many glare sources the occupant is experiencing will determine how the detected glare source pixels are treated. If a particular occupant said that they experienced two glare sources for the scene they would be able to indicate the azimuthal and tilt angles that each glare source was contained within on the angular mesh.

The luminance for each glare source was then found by calculating the average luminance of the detected glare pixels (shown in Figures 5 and 6). The solid angle for each glare source was contained within on the angular mesh.

The luminance for each glare source was then found by calculating the average luminance of the detected glare pixels (shown in Figures 5 and 6). The solid angle for each glare source was determined by adding the solid angle
subtended by each glare pixel for the glare source. The vision axis can be used to calculate the angle between the detected glare source and line of sight.

The magnitude of discomfort glare experienced from these glare sources was calculated using the Daylight Glare Index (DGI). Both View 1 and View 2 were analysed with the consideration there were two distinct glare sources in each scene. The results are tabulated for each of the two glare scenes in Table 1. The table specifies the vision axis and location of the glare source using the azimuthal and tilt angles respectively. Vision axes for each scene were chosen for an occupant looking directly into the centre of the computer screen.

### Table 1  Results for field images (View 1 and 2)

<table>
<thead>
<tr>
<th>No</th>
<th>Bgrd Lum (cd/m²)</th>
<th>Location [azi, tilt]</th>
<th>Vision Axis [azi, tilt]</th>
<th>Solid Angle (sr)</th>
<th>Glare Lum (cd/m²)</th>
<th>DGI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.33</td>
<td>[37,79]</td>
<td>[10,90]</td>
<td>0.032</td>
<td>4800</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[55,36]</td>
<td></td>
<td>0.039</td>
<td>3130</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11.5</td>
<td>[87,339]</td>
<td>[10,30]</td>
<td>0.024</td>
<td>14800</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[75,12]</td>
<td></td>
<td>0.003</td>
<td>23100</td>
<td></td>
</tr>
</tbody>
</table>

Both glare sources were determined to be “intolerable” from the DGI ratings. View 1 has the most glare subtended at the eye but this only occupied 0.35% of the total fisheye pixels. Thus our assumption that the scenes contained only small area glare sources remained valid.

### 4. Concluding remark

This investigation has successfully integrated luminance mapping techniques and analysis that allows quick and accurate assessment of a visual environment with respect to the physical parameters of discomfort glare. Using digital cameras to capture wide luminance variations offers lighting designers an affordable alternative to CCD imaging technology and a practical advantage over using spot luminance meters. The authors would like to invite all interested parties to participate in this research through collecting data in situ to help build a database of discomfort glare measurements. With the ability to conduct large scale studies on discomfort glare in complex lighting environments, our understanding of the factors that influence it will improve. Detailed information for those who would like to participate in this research can be found at [http://www.lighting.qut.edu.au/rdc/glare/](http://www.lighting.qut.edu.au/rdc/glare/).

### References


*Figure 2 to 6 appear in color on J-STAGE: [http://www.jstage.jst.go.jp/browse/jlve/*](http://www.jstage.jst.go.jp/browse/jlve/*)