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# High Dynamic Range Image Based Graphical User Interface For Glare And Uniformity Analysis

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## Abstract

Camera based luminance measurement and analysis are increasingly used for the study of interior lighting in daylight-artificial light integrated schemes. This paper describes the development of a Graphical User Interface (GUI) system capturing a set of 11 exposure bracketed images, creates high dynamic range image and calibrates the camera to get the absolute actual luminance of a scene, and analyzes glare, contrast and uniformity. The calibration is done with Gretag Macbeth Digital Color Checker SG and standard luminance meter

- Konika Minolta LS100 where the reference curves are obtained by experimentation with different exposure values. Glare analysis is done based on three cases; glare condition is set five times the average luminance of the scene, the threshold of luminance set at 2000 $Cd/m^2$ and threshold set as four times the average luminance of the task area. In addition to luminance distribution of any scene the minimum, maximum and average of any scene luminance as well as the uniformity ratios of any selected region can be obtained. It is possible to select task area, adjacent area and remote area which helps in setting contrast ratios that are in the permissible range. Deployment of this GUI makes a low cost computationally efficient, stand-alone system for glare and uniformity analysis.

**GUI, glare analysis, luminance distribution, contrast, uniformity, high dynamic range image**

## 1.0 Introduction

Discomfort glare is an important concern of day-lighting design. Though most lighting designs are based on illuminance calculations, visual discomfort can be well described in terms of luminance which indicates the brightness perceived from the scene **(Mead, 2011).** The term luminance describes the intensity of light emitted from a particular area and its unit is $Cd/m^2$. Glare is a subjective response, many models exist to evaluate the glare but none of them fit the data completely. Here the following questions arise: Can High Dynamic Range Image (HDRI) be used to assess discomfort glare conditions? Is it possible to identify the relative value of luminance which makes a pixel count of a glare source? Can we assess uniformity and contrast? Recently **Cai and Chung, (2011),** proposed HDRI photogrammetry for the evaluation of discomfort glare. A single digital camera fitted with wide angle or fish eye lens could measure per pixel synchronous luminance and geometry data across a scene. It is possible to acquire millions of data points in single measurement. The authors carried out analysis with the help of Excel spread sheet, an efficient supporting computer program which made the analysis easier **(Cai, 2013)**. A GUI which can produce the luminance distributions and graphically represent the results of analysis simplifies the task of interior glare and uniformity analysis.

High dynamic range imaging is increasingly used for the quality and quantity evaluation of luminance in daylight-artificial light integrated schemes. Instead of luminance measurement using point-by-point devices, measurements can easily be made with a digital camera. If the luminance of a scene can be accurately measured using the camera, a novel system of building automation can be developed that uses camera as a sensor in replacement of occupancy and photo-sensors **(Inanici, 2006).** HDRI is used for luminance measurement so as to develop an image that closely resembles to what a human eye can see. For this purpose the radiance information is extracted from the set of multiple exposure low dynamic range (LDR) photographs and the imaging device needs to be calibrated in order to get absolute luminance for general lighting applications. Since this process deals with matrix operations, it is easy to implement in MATLAB (www.mathworks.com).

There are four different ways of measuring luminance. They are:

1. Using a luminance meter;
2. By measuring illuminance using luxmeter and subsequent calculations;
3. Using a digital imaging photometer;
4. By High Dynamic Range Imaging (HDRI) technique which is the latest technology being utilized in this work.

Photography is a tool which can capture the complete range of luminance within a large field of view at high resolution in a cost effective manner. The HDR imaging technique utilizes multiple photographs of the same scene at different exposures. The dynamic range of a scene is the ratio of maximum scene luminance to the minimum scene luminance and the dynamic range of a camera is the ratio of luminance of lightest to the darkest pixel. The photograph sequence is fused to form a single HDR image using the self-derived camera response function. Formation of HDR image using photographs at varied exposures of a scene of high luminance range has been studied by many researchers **(Debevec and Malik, 2008), (Madden, 1993), (Moriwaki, 1994), (Yamada, et al., 1994).**

HDRI can be used in many scientific applications such as glare analysis, luminaire performance testing, luminance and contrast analysis and human vision simulation **(Guglielmetti, et al., 2011).** Because of the range of fields in which HDRI finds application its accuracy is being investigated further by many researchers **(Moeck, and Anaokar, 2006), (Inanici, 2010), (Konis, et al., 2011).** Luminance calibration, using any of the standard sources gives calibration factor which is the relation between the luminance measured by a luminance meter and the output of the HDR image forming software. Applying the calibration factor for the luminance values of HDR images, the true luminance can be calculated at any desired point.

## 2.0 General description of the system

LDR images are taken by Nikon DSLR D5100 with 35mm f/1.8 G prime lens and Canon 60D – EF S18-135 IS lens using exposure bracketing method and the images are sent to PC using Eye-Fi Connect X2 SDHC, Wi-Fi Memory Card. To capture the entire range of the scene luminance, multiple exposure images of the scene are taken. The images captured are instantly transferred to a PC wirelessly using Wi-Fi based memory card, thus keeping the data ready for immediate analysis. A GUI is developed to process the data and compute the actual luminance of different surfaces of the scene. Gretag Macbeth Digital Color Checker SG and standard luminance meter - Konika Minolta LS100 are used to calibrate the camera. The developed GUI will carry out camera calibration as well as quantify quality analysis of the scene.

## 3.0 Camera Calibration for luminance measurement

The camera parameters that are important for photography related lighting analysis are aperture, shutter speed, ISO and exposure. A digital camera needs to be calibrated before it is used to measure luminance of a scene. Konica Minolta LS100 luminance meter is used for the calibration of luminance measurement where the unit of measurement is in Cd/m$^2$. The flowchart for camera calibration given in Fig.1 is well explained by the authors in their previous paper **(Kumar, et. al, 2014).** Eleven LDR images of the same scene are used for producing HDR image of the scene in MATLAB. Luminance (L) is calculated as:

$$L = k * (0.2127 * R + 0.7151 * G + 0.0722 * B)\,Cd/m2 \qquad (1)$$

Where R, G and B are the values obtained for Red, Blue and Green colors from HDR image.

Using equation (1) the luminance of each and every pixel is calculated as $L_{mat}$. The luminance meter readings, $L_m$, and $L_{mat}$ are plotted for various exposure values. From these curves, the curve which gives minimum error is selected as the reference curve. For all further calculations this reference curve is used as basis and the new luminance values are calculated for any exposure value. Figure 1 shows the flow chart for calibration.

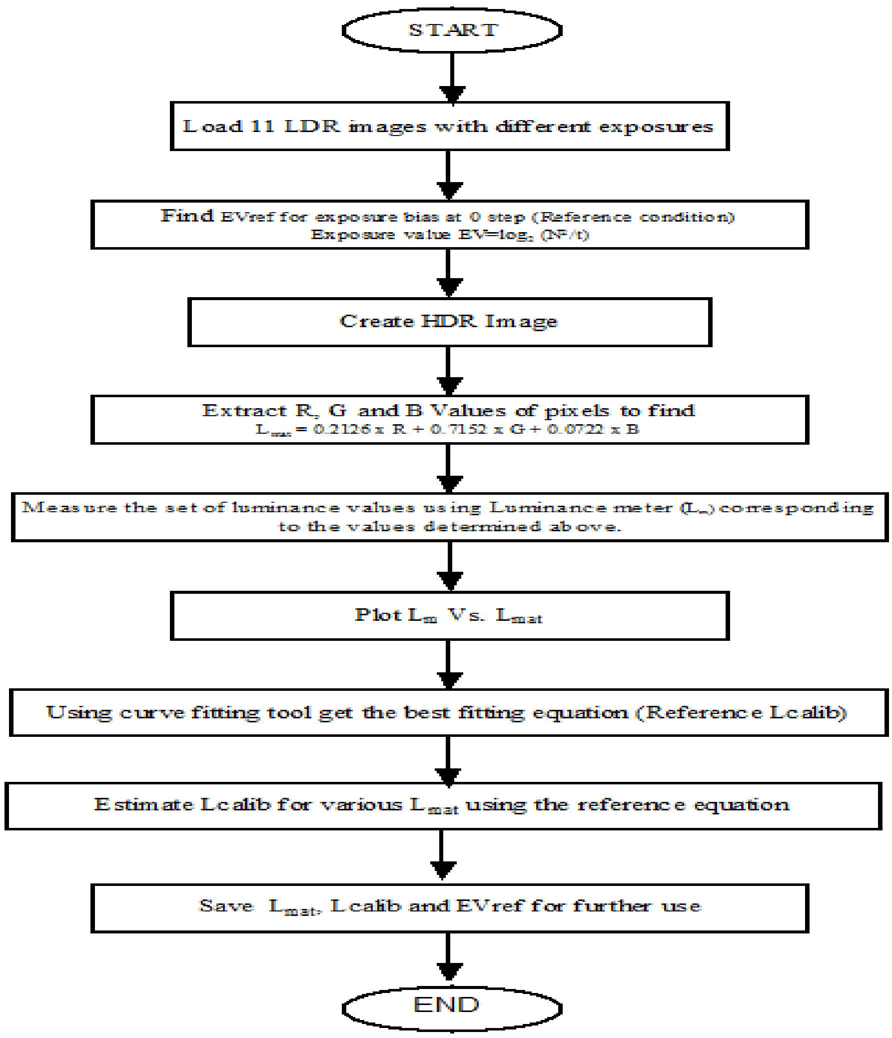


**Figure 1:** Flow chart for calibration

Once the luminance values are calculated for the entire scene, analysis for glare, contrast and uniformity are done for various conditions.

## 4.0 GUI for Glare, Uniformity & Contrast

### 4.1 Glare Analysis

There is not much theoretical understanding of discomfort glare, and every formula evaluates glare differently. There is no real measure of how well the different models fit the data. Evaluating glare in complex scenes may require fundamental changes to the form of the glare models **(Clear, 2012).** As discussed in the literature **(Doyle and Reinhart, 2010),** glare detection approach is based on three cases which are considering average luminance of the complete scene, assuming a set value of luminance and average luminance of task area **(Kumar et al., 2014), (Van, 2009)**.

Three cases considered are described below:

- Case 1: Considering average luminance of the complete scene – Here the average luminance of all pixels in the image is calculated and a luminance value greater than 5 times average luminance is detected as a glare source.
- Case 2: A set value of luminance – Initially a threshold value is set for example in the case of a normal room with suitable lighting, any pixel luminance greater than 2000Cd/m$^2$ is considered as glare.
- Case 3: Considering average luminance of task area – Selecting a task area for which the luminance average is calculated and a value greater than 4 times the average luminance of task area is considered as threshold for glare source detection.

The flow chart showing glare detection algorithm is presented in Figure 2. For those image pixels which are greater than the threshold value, the blue pixel luminance value is get to 255 and red and green values are set to 0 and the other pixels remaining the same. Therefore the glare will be indicated in the image by blue colour.

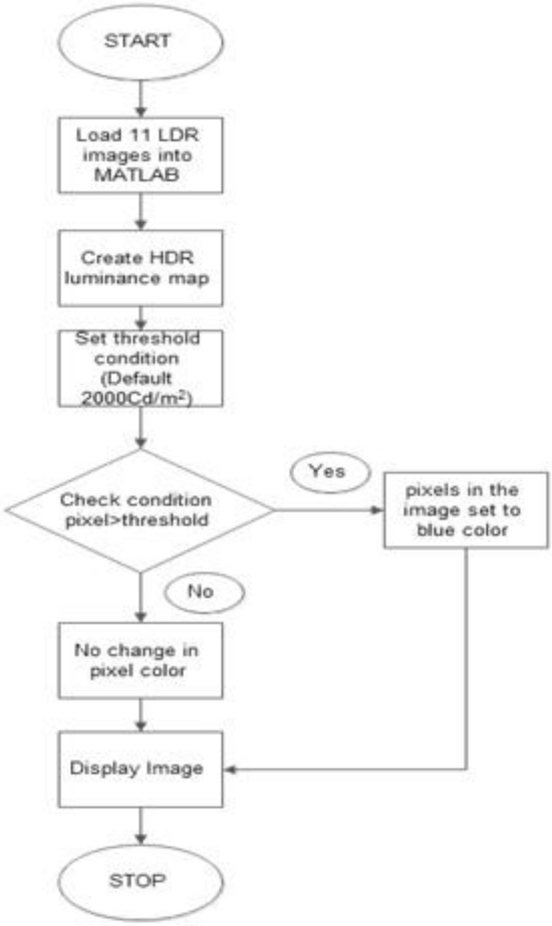


**Figure 2**: Flow chart for glare detection algorithm

To present the analysis a set of images taken at 9.15am is used and the results of three cases are shown in Figures 3,4 &5. Figure 3 shows the case where glare condition is set as five times the average luminance of the scene, Figure 4 shows the case where threshold is set at 2000Cd/m$^2$ and finally, with glare condition is set as four times the average luminance of the task area as shown in Figure 5.

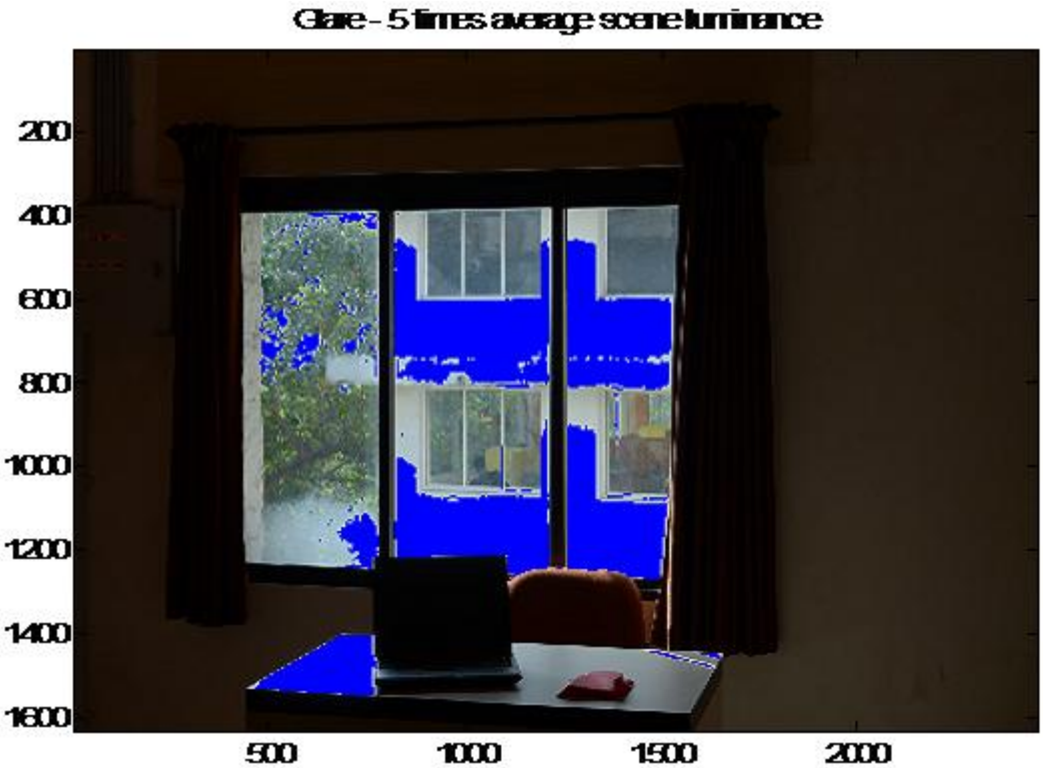


**Figure 3:** Glare condition set as five times the average scene luminance

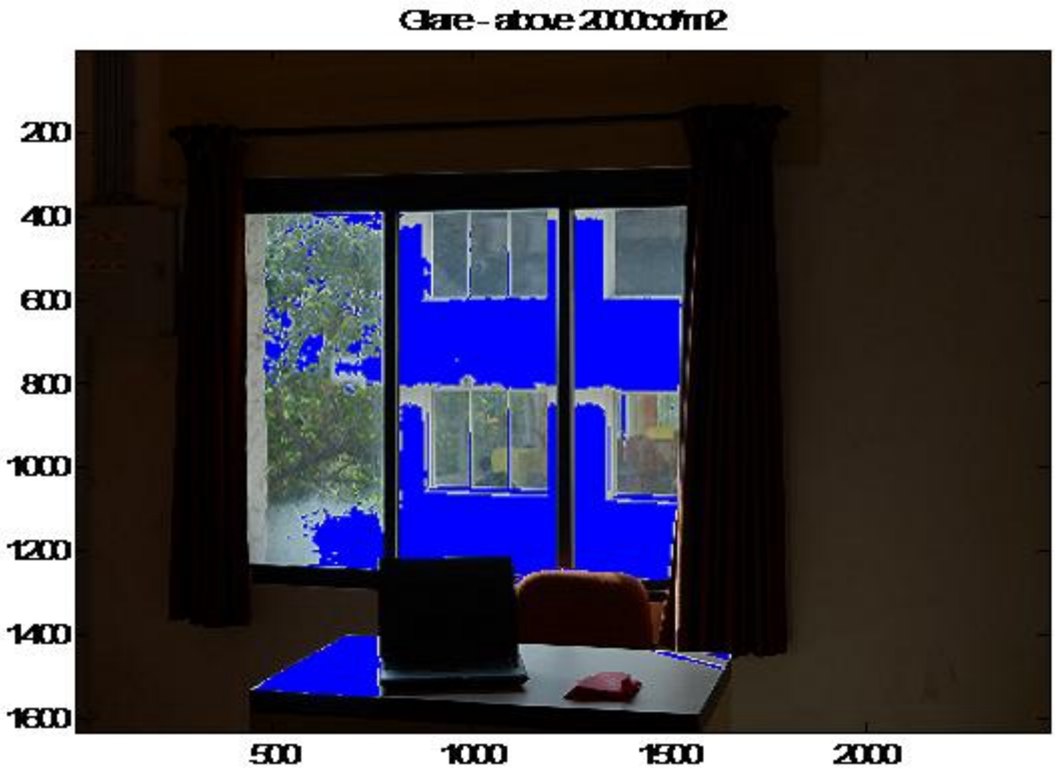


**Figure 4:** Glare condition set as 2000Cd/m$^2$

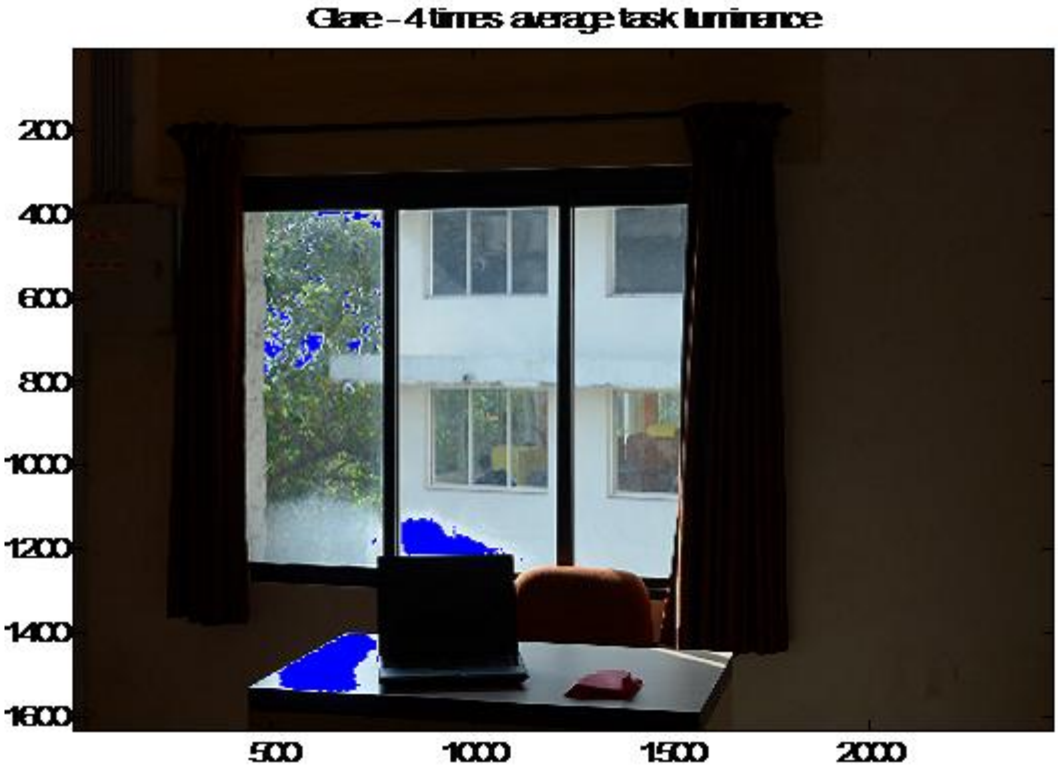


**Figure 5:** Glare condition set as four times the average luminance in the task area

On repeating the above analysis with different timings, it is observed that case 1 and case 2 have similarity, whereas defining a task area for the 3rd case is not comparable in all cases. Setting a value four or five times the average scene luminance or task luminance is not justifiable because this multiplied value may not create glare to all humans. Glare is a subjective condition and it varies with each and every person. Generally a luminance value of 2000Cd/m$^2$ is considered as reference for glare in most case studies. Therefore for further part of the work, this threshold value is considered for glare analysis.

The set of images taken at 9.15 am is analysed using Photosphere – Evalglare combination in which photosphere (www.hdrsoft.com/download/mac.html) will form the HDR image and the software Evalglare (www.sbi.dk/download/pdf/Evalglare.pdf) analyse the glare and it is observed that Figure 6 gives comparable results i.e. the results show closeness for case 1&2 in which the threshold is fixed.

**Figure 6:** Glare condition analysed using Evalglare

Figure 7 presents the changing glare conditions with time, photographs of the same scene are taken for 9.15 am, 10.15 am, 11.15 am and 12.15 pm, and observed using the system developed. It is seen that during the morning hours the glare is dominant over the window side and reducing towards noon.

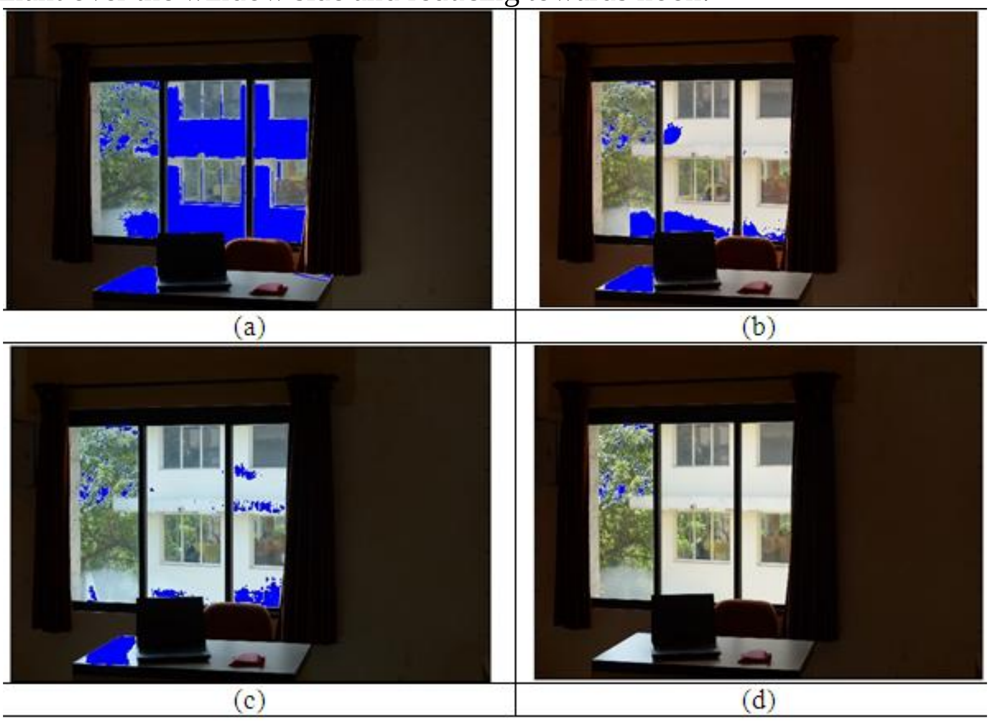

**Figure 7:** Glare condition analysed for images taken at different timings: (a) 9.15 am, (b) 10.15 am, (c) 11.15 am and (d) 12.15 pm

**4.2 Uniformity and contrast**

The photos are taken during the morning hours where the sunlight is more on the right side of the room. Photos are taken and analyzed considering three zones, zone 1 towards the left, zone 2 at the middle and zone 3 at the right end of the room. A MATLAB code using the *region of interest tool* is used to analyze the general uniformity inside a room considering zones.

Table 1 shows the average luminance values obtained for each zone for different lighting conditions described in Figure 8.


**Figure 8:** Three cases to study zoning (a) all windows closed with artificial lights only, (b) right side- windows open and lights on and (c) both side windows open with daylight only

**Table 1:** Zone luminance for different lighting conditions

| Condition | ZONE 1 (in $Cd/m^2$) | ZONE 2 (in $Cd/m^2$) | ZONE 3 (in $Cd/m^2$) |
|---|---|---|---|
| Case 1 | 33.2462 | 47.0406 | 37.4096 |
| Case 2 | 23.4064 | 36.2417 | 118.2570 |
| Case 3 | 85.4164 | 41.0742 | 130.1709 |

Contrasts on visual display units (VDU) create discomfort to the occupants in offices and workplaces. It can be minimized by reducing the contrast between the foreground and background area on the screen of a monitor. IESNA defines the luminance contrast as the relation between surfaces with greater and lower luminance as in equation (2) where C denotes contrast, $L_g$ greater luminance and $L_l$ being the lesser luminance. The result of this equation indicates a contrast between 0 and 1. The task area and background area is selected and average luminance is calculated to find the contrast luminance **(Wuller and Gabele, 2007).**

$$C = \frac{L_g - L_l}{L_g} \qquad (2)$$

IESNA recommends some limitations to Luminance ratios in an office environment such that the background luminance gets balanced with task luminance. Recommendations are that luminance of task area to adjacent surroundings and task area to remote surroundings must not exceed 3:1 and 10:1 respectively **(The IESNA Lighting Hand Book, 2010).**

After the calculation of luminance matrix, the 8 bit image id is displayed where the region of interest can be selected using ***impoly*** function in MATLAB for the calculation of luminance contrast with the whole image considered as background. To find the Luminance contrast between surfaces with greater and lower luminance, equation (2) is used.

To find the uniformity over a work plane, where the reflectance of surface remains the same, the luminance ratios are calculated. The spatial luminance distribution of the entire scene also is determined.

### 4.3 GUI for glare, contrast and uniformity

In the GUI system developed for the analysis of glare, uniformity and contrast, a front end window as shown in Figure 9 opens up which loads the eleven LDR images as shown in Figure 10. The twelfth photo is the intensity image of the eleventh image which is introduced for uniformity of display.

Figure 11 gives luminance curves at the reference exposure value ($EV_{old}$) and at the exposure value of the input image at zero step ($EV_{new}$).

Per pixel analysis of the image is done to evaluate the luminance distribution where the image is false coloured or pseudo coloured to notice the variation in luminance within the image and the glare is detected when the pixel luminance value exceeds $2000 Cd/m^2$. Contrast evaluation is shown in Figure 12.

The area or region of interest selected can be identified in Figure 13. The average luminance of the selected area along with the average luminance of background area are used for calculating contrast.

It is possible to select different regions of interest, namely, task area, adjacent area and remote area which are needed in contrast analysis. This method helps to assess the standards for luminance contrast as per IESNA. The messages generated at the end of analysis are shown in Figure 14. Image luminance details such as maximum luminance, minimum luminance and mean luminance can also be displayed.

Finally a standalone executable GUI with the '*deploytool*'(www.mathworks.com) is formed by including all the necessary toolboxes and files.

**Graphical user interface (first page)**
**Screen shots**

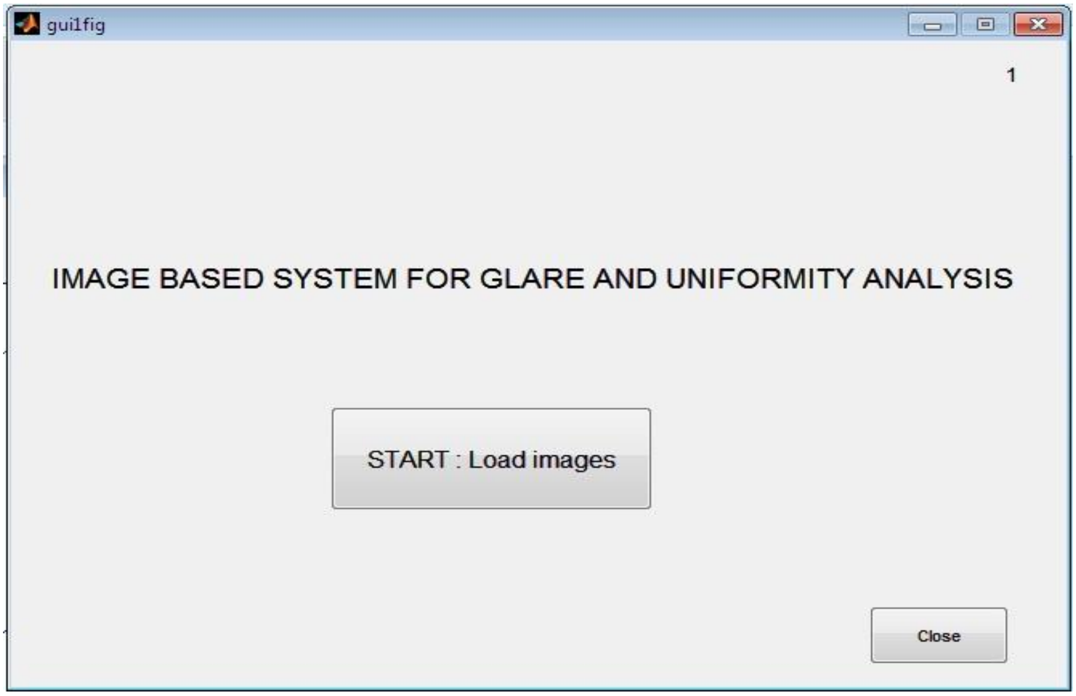


**Figure 9:** Opening page of GUI system

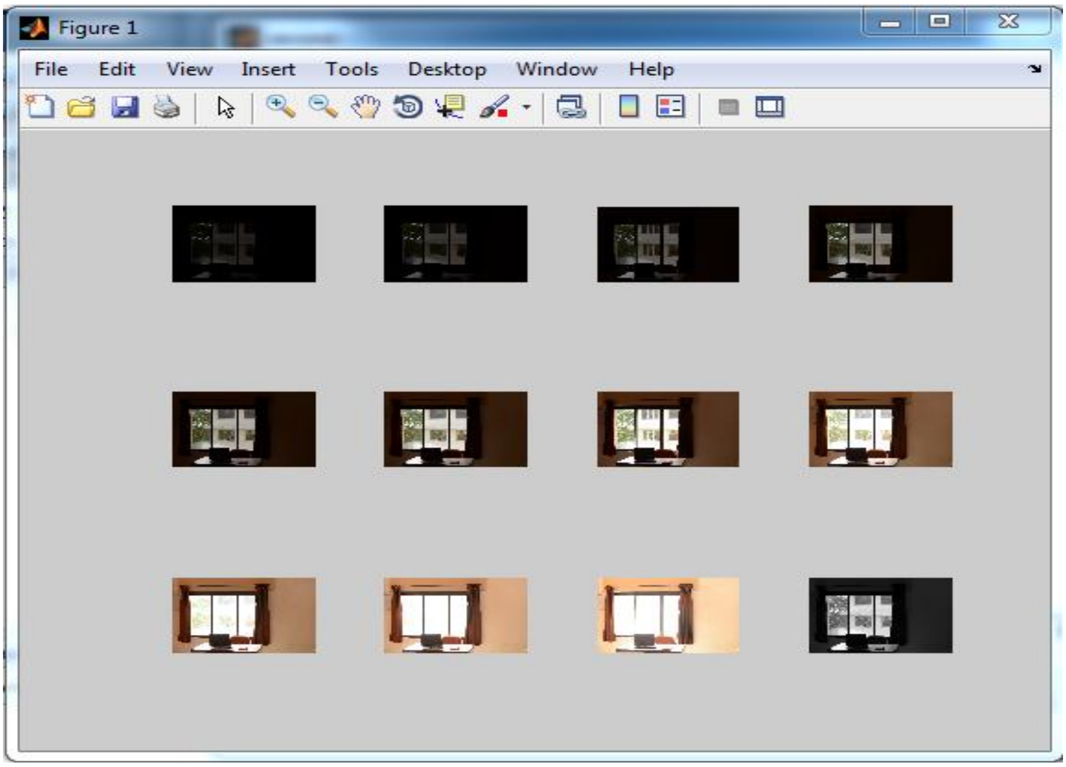


**Figure 10:**.Multi-exposure images from selected image folder

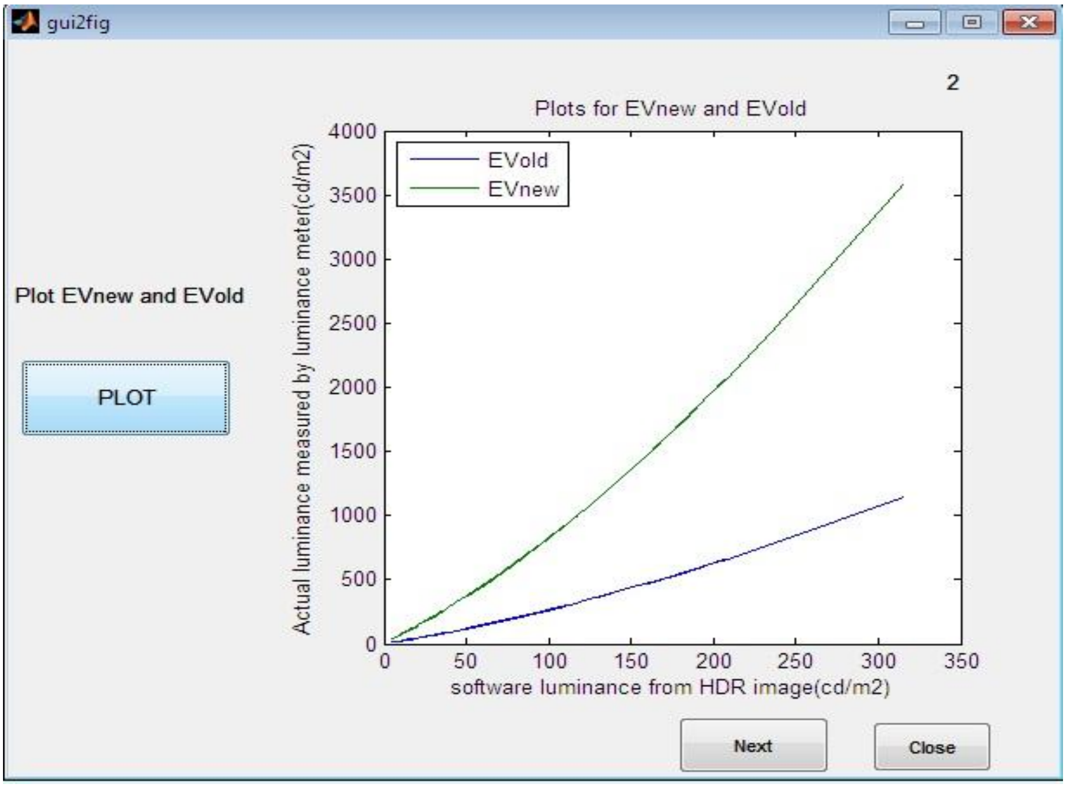


**Figure 11:** Plot of luminance curves

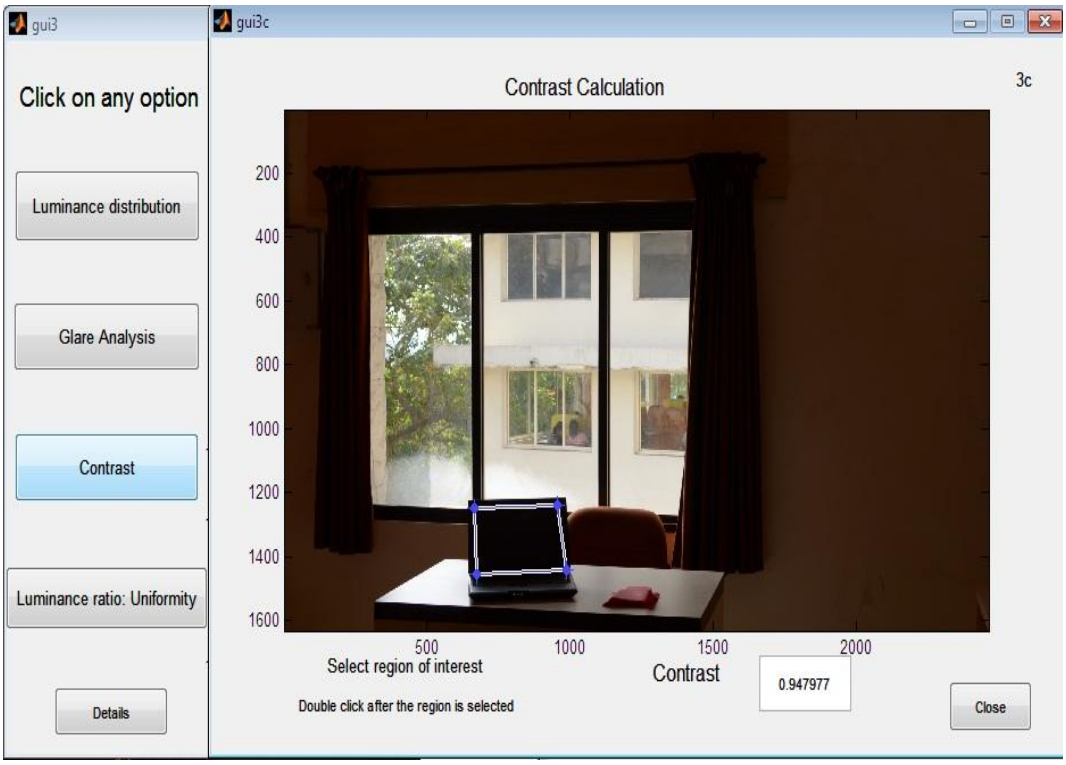


**Figure 12:** Contrast evaluation

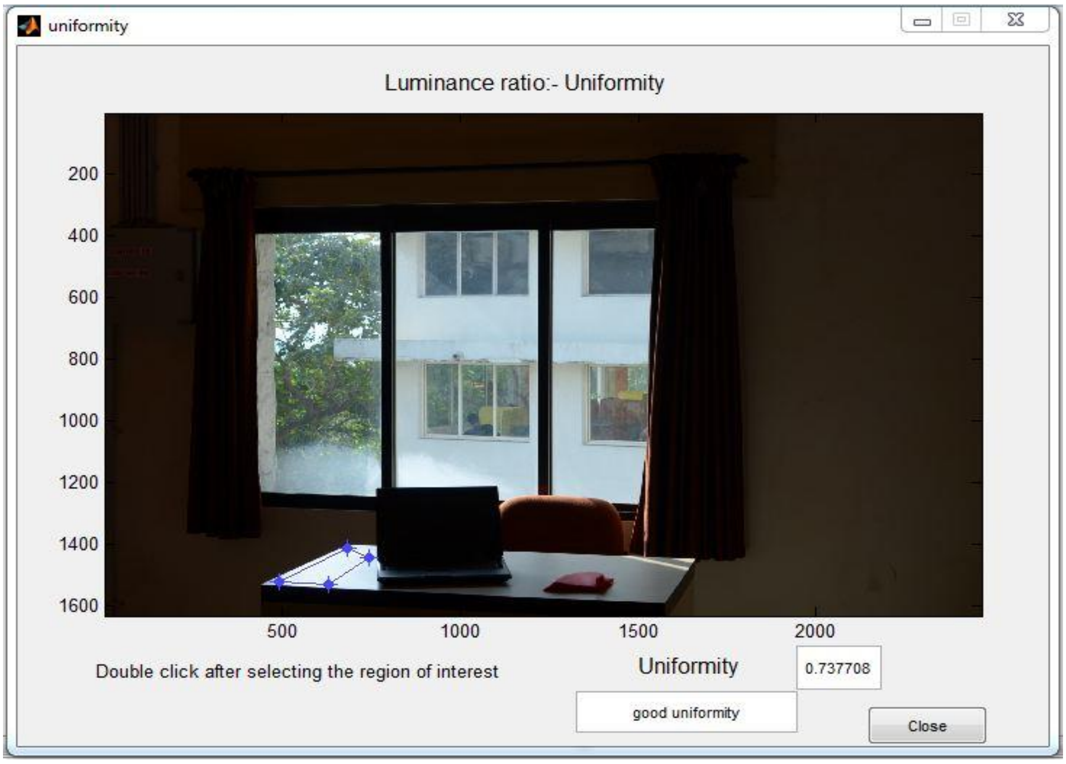


**Figure 13:** Uniformity over work plane

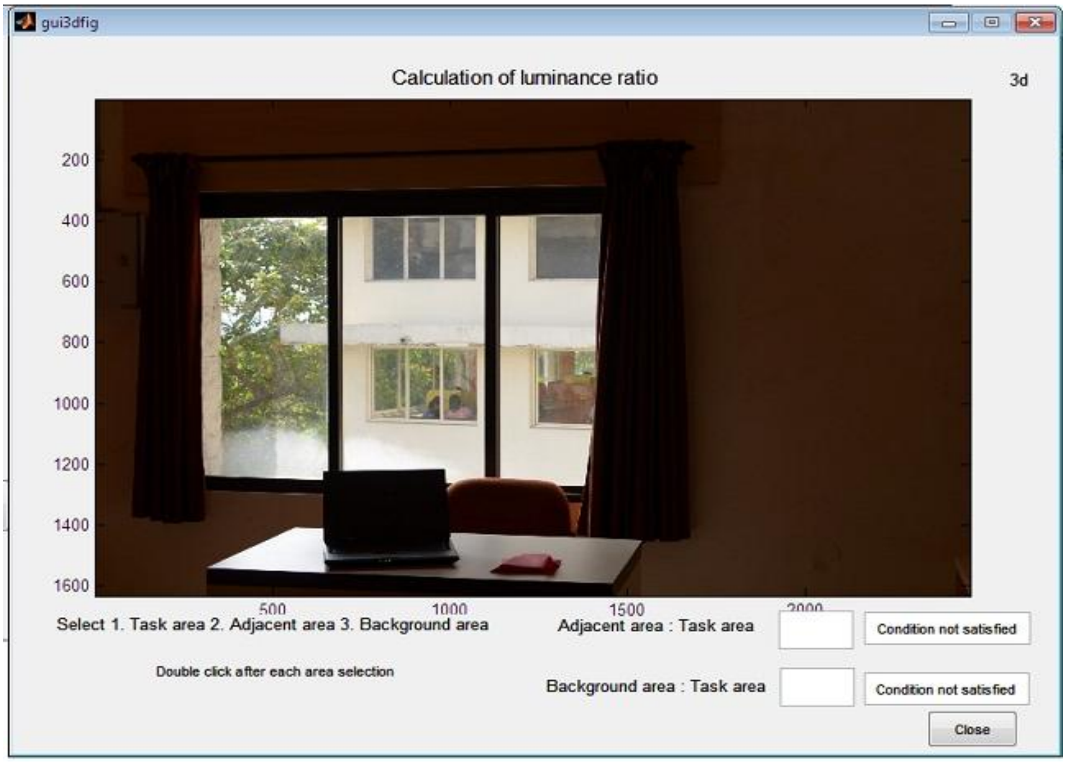


**Figure 14:** Luminance ratio calculation

**Conclusions**

The Graphical User Interface (GUI) developed helps in analysing the interior luminance distribution, glare and contrast. The ability to create photo-metrically accurate images of scenes and use them in experiments conducted over the internet is an exciting prospect that would enable the effects of light distribution to be explored more easily. Developing a cost effective stand-alone system, for image based photometric measurement and analysis, will be a beneficial tool for lighting designers. More intensive research is required to make a reliable system for various applications. As the lighting recommendations change from horizontal work plane illuminance to spatial luminance distribution, an image based system only can provide the required information. An accurate image based system will make it possible, the prediction of visual comfort of real windows with daylight variation, as well as for the design of virtual natural lighting solutions.

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