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Algorithm of HDR image preparation for discomfort glare assessment

Abstract *The CIE UGR is the widely applied measure of a discomfort glare in the interior working environment. An array photometer allows calculating the UGR according to the international standards, but a range of luminance dependent on a source of light can exceeds considerably capabilities of camera matrix sensor. High Dynamic Range Imaging (HDRI) technique solves this problem. In the article an effective algorithm of preparing the set of photographs for creating HDR images in UGR calculation was proposed.*

Streszczenie. *UGR jest powszechnie stosowanym parametrem do oceny olśnienia przykrego we wnętrzach. Detektor matrycowy pozwala wyznaczyć wartość UGR zgodnie z przyjętymi normami międzynarodowymi. Aby uzyskać odpowiednio szeroki zakres rejestrowanej luminancji stosowana jest technika obrazów o podwyższonym zakresie tonalnym (HDRI). W artykule zaproponowano efektywny algorytm przygotowania serii zdjęć HDRI na potrzeby pomiaru UGR.* ***(Algorytm przygotowania obrazów o zwiększonym zakresie tonalnym dla oceny olśnienia przykrego)***

Keywords: discomfort glare assessment, UGR, HDRI, array photometer.
Słowa kluczowe: ocena olśnienia przykrego, UGR, obrazy o podwyższonym zakresie tonalnym, fotometr matrycowy.

Introduction

The CIE Unified Glare Rating (UGR) of the lighting installation is the practically applied measure of the discomfort glare. Applying the known formula the value of UGR is calculated on the basis of the luminance of sources of glare and the background luminance. Calculation of the UGR can be made in proper way on the base of measurements applying the array photometer, but in practice the matter is not so simple.

A range of the luminance which must be acquired during measurements is the main problem. The human eye is able to register a wide range of luminance (about 10^{15} times of minimum recognizable value [1]). The wide range is also necessary to register differences of the luminances, when the discomfort glare occurs. This range exceeds considerably capabilities of camera matrix sensor as well. In such a situation, in order to get the correct map of the luminance for the UGR calculation, the High Dynamic Range Imaging (HDRI) technique is used. However the most important problem is acquiring correct exposure to series of photographs for creating the HDRI. Even the small error of exposure conditions causes the considerable error of the *UGR* calculation. This task requires proper algorithm how to obtain the series of photographs with correct exposure.

UGR and discomfort glare assessment

We can experience the discomfort glare practically in every conditions, when in the visual field appears a bright area with a luminance considerably higher than the background. This area can be simply an observed source of light or can come into existence as a result of reflection (or refraction) of light. This phenomenon is not only unpleasant to people, but it also reduces visual capabilities, it makes difficult the performance of work, and in many cases can also constitute an indirect reason of occupational accidents. For this reason a great weight is being put for ensuring adequate lighting conditions, especially glare limitation, in a working environment.

Publications of the International Commission on Illumination (CIE) [2, 3] determine principles and methods of discomfort glare control in interiors. These principles were implemented in the European Standard EN 12464-1 [4]. On the basis of experimental research the mathematical model was proposed [3] and the formula for determining Unified Glare Rating (UGR) was applied (1).

(1) $$UGR = 8\,log\left(\frac{0.25}{L_u}\sum_i \frac{L_i^2 \omega_i}{P_i^2}\right)$$

where: L_u– the background luminance (cd/m^2), L_i – the luminance of glare source i in the direction of the observer's eye (cd/m^2), ω_i – the solid angle of the glare source i seen from the observer's eye (sr), P_i – the position index (Guth's index) for the glare source i (displacement from the line of sight) according to Guth analysis – it can be taken from the adequate table [3].

Such a formula of calculation (1) requires both photometric and geometric parameters to be determined. It is worth pointing out, that practically there is a very difficult task to calculate UGR in accordance to this formula. It means that the assessment of the discomfort glare is most often carried out with approximate methods. It can be analyzed at the stage of the illumination project or in real conditions in the existing room. In both cases it is, however, estimated evaluation, not based on luminance measurements. One could hazard a guess that only applying the array luminance photometer allows calculating UGR in accordance to formula (1) and to international standards. This way, the correct measurements of the parameters required in formula (1) becomes an essential task.

Human vision system

The eye can be simply treated as the optical instrument with two main elements [5]: the convergent lens and the retina, where picture is projected. The pupil (the hole controlled by the iris) regulates amount of the light falling into the eye. There exist two kinds of receptors in the retina: rods (approx. 120 million) and cones (approx. 6 million). Rods are responsible for the low light (scotopic) vision. They allow distinguishing black, white and tints of grey – monochrome information. Rods inform us about shapes and contours in dim light, but cannot give information about color. The scotopic vision regime applies to luminance levels below 0.003 cd/m^2 [6]. Cones are responsible for the bright light (photopic) vision. They allow distinguishing color but they require the high ambient light levels to stimulation. The photopic vision regime applies to luminance levels bigger then 3 cd/m^2 [6]. Mesopic vision relates to light levels between scotopic and photopic vision regime (0.003 cd/m^2 – 3 cd/m^2).

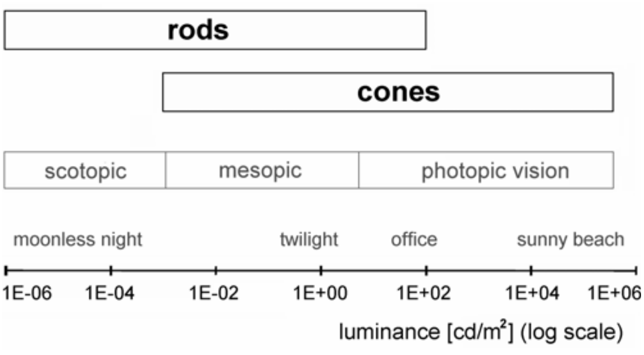

Fig.1. Dynamic range of luminance perceived by human visual system

So complicated human visual system (controlled pupil and set of different receptors on the retina) allows receiving a very large range of luminance (0.000001 cd/m^2 to 100 000 cd/m^2) [5, 7] (Fig.1). It is incredible that we can distinguish details in moonlight as well as at sunny high noon. Such a huge range of luminance cannot be unfortunately achieved by contemporary technical (measuring) instruments. On the other hand, the phenomenon of the discomfort glare is in the natural way associated with a wide difference of luminance between the background of the visual field and dazzling sources.

Light in photography

Practically, the array photometer as a system of the digital camera with the relevant software could be used as an effective measurement system of discomfort glare. It allows creating the map of the luminance, and calculating the UGR value on the basis of the relevant algorithm.

In photography the exposure of a photosensitive material or matrix sensor (CMOS or CCD) depends on three parameters [8]:

- photosensitivity – it is a parameter which determines image sensor's sensitivity to light. It is described as ISO speed and is expressed as a number in a geometric progression (50, 100, 200, 400 …etc),
- time value (TV) (shutter speed) – it determines time of exposure – the length of time when camera's shutter is open,
- aperture value (AV) – it refers to the relative diaphragm opening inside a lens. It is described by f-number. The higher f-number – the smaller aperture opening and less amount of light reaches the sensor.

Exposure value (EV) is a parameter that joins above mentioned parameters and describes the photographic lighting conditions. It is defined by formula (2). An EV value increase by 1 corresponds to the opening the aperture of one step or to use twice longer exposure time.

(2) $$EV = log_2 \frac{f_{AV}^2}{TV}$$

where: f_{AV} – relative aperture value (f-number), TV – time value in seconds.

The EV values are being given for the specified value of sensitivity. Most often for 100 ISO. Of course there exists a possibility to recalculate exposure condition (EV value) for different sensitivity (3).

(3) $$EV_{X\_ISO} = EV_{100} + log_2 \frac{X\_ISO}{100}$$

where: EV_{100} – exposure value for sensitivity 100 ISO, EV_{X_ISO} – exposure value for sensitivity X_ISO.

Formally EV is not a measure of luminance (or illuminance). However EV value corresponds to the luminance for nominally correct exposure of a picture [8]. Of course it is worth pointing out, that in photography proper exposure means correct exposure for average level of 18% grey in the picture. Calculation of the luminance in this situation is more complicated. Theoretically it can be simplify by an exponential function, but in practice it requires sensor and camera's optic analysis and proper calibration.

The exposure range for typical room (flat, office) is approximately 6 – 8 EV. But the source of light in a visual field extends this range dramatically. It can achieve 20 EV or more. It is widely assumed that human visual system can achieve a range of 14 EV. Typical range of photographic sensor (CCD or CMOS) is only 6 – 8 EV (with tonal precision 3 x 8 bits per pixel) [9]. Additionally it is limited by noise in low (black) level of a picture. So there is a problem how to record the wide tonal range for the discomfort glare assessment. The good solution of this problem is High Dynamic Range Imaging (HDRI or HDR) technique. HDRI consists in capturing multiple standard photographs using exposure bracketing and then merging them into one image [10].

HDRI in luminance measurement - where is the problem

TechnoTeam's LMK photometer (LMK Mobile and Advance) [11] is a matrix system where a Canon EOS 550D digital camera is used. This camera is equipped with CMOS sensor in 5184 by 3456 pixels resolution. SIGMA Circular Fisheye 4.5mm F2.8 EX is used as a lens, when LMK photometer determines UGR. AEB (Auto Exposure Bracketing) mode allows taking series of 3 pictures with varying exposure parameters [12]. Typically: standard, decreased and increased exposure, with maximum of 2 steps (2 EV) increment. TechnoTeam's software builds high dynamic range image. On the base of 3 photos taken at different exposure conditions HDRI technique allows increasing the luminance range by 4 EV in LMK photometer. In the LMK software the luminance is stored in the proper HDR file – the pf format is used. It allows approaching the dynamic range of the photometer to the human visual system. However the difference between the luminance of sources and background is comparable for human visual as well as for LMK photometer. It means that correct setting of exposure conditions for HDRI series is very important task. Improper exposure does not allow taking in proper way the light sources and the background in luminance range.

We curried out set of experiments for different lighting conditions and for different working regime of photometer. Our experiments showed that the discomfort glare assessment in such conditions could determine serious errors. We tried to determine UGR in prepared model of working environment using LMK system (photometer and software). Measuring windows of the LMK system for an example of improper exposure are shown in figure 2. The LMK system is equipped with a circular fisheye lens, so the taken photo is in a round form.

Algorithm for preparation of HDR images

Operating manual to the LMK system [11] suggests that the selection of the exposure time for series of photographs for the glare assessment should be done on the basis of the average level of the luminance. In our opinion it is not a good solution – in many cases it causes, at least, doubts related to realization, and often measuring errors. The algorithm introduced in our paper is based on a little bit different principles. We assume that in order to reach the correct glare assessment the maximum dynamic range available in the LMK photometer should be used. It simply means that the border value of this range must correspond to the maximum value of the light sources luminance. This value is known – it can be simply measured by the luminance meter. So this way the aim of algorithm is to calculate the TV (shutter speed) for series of HDR images which allows covering dynamic range where the maximum value is defined by luminance of selected light sources.

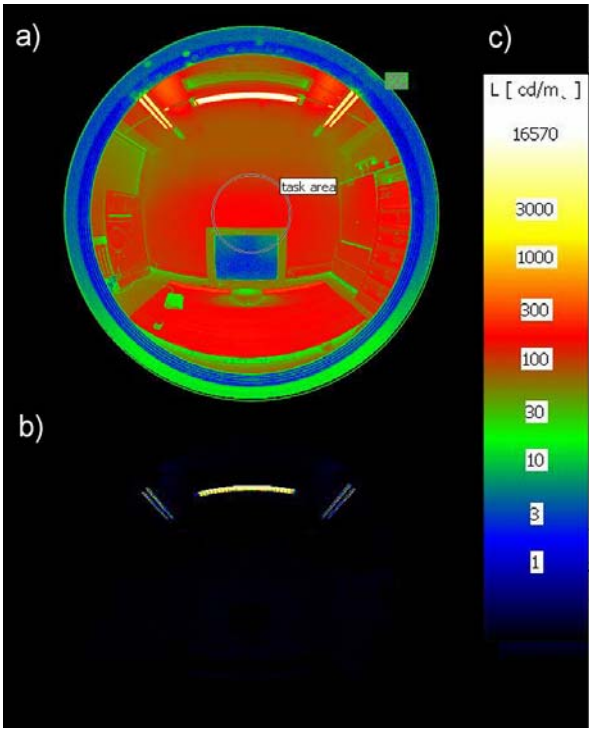

Fig.2. Windows from the LMK system software. a) view from circular fisheye lens, b) masked places of highest luminance, c) luminance scale. Starting shutter speed was set not in proper way – the masked light source have in fact higher luminance (24500 cd/m^2) than presented in scale calculated by software. This way calculated value of UGR was too low. Error reached approximately level of 30%.

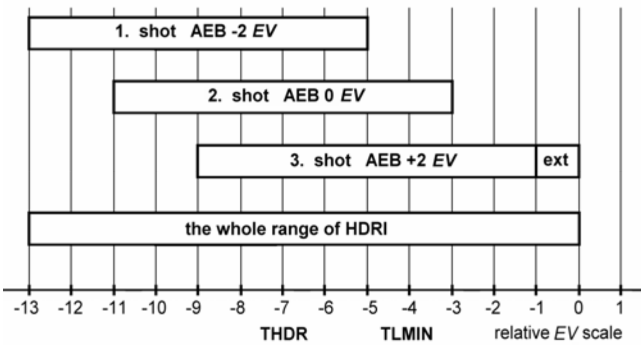

Fig.3. The whole dynamic range of the series HDR images for discomfort glare assessment. The scale of exposure is relative – 0 *EV* indicates level of the brightest places of the taken picture (from the observer position). "ext" denotes suggested extension of the range of one picture about 1 EV towards the high luminance

The main instrument of the LMK photometer is the Canon camera model 550D. Analyses of independent laboratories [13, 14] report, among other things, the dynamic range of the sensor of this camera with assumption that sensitivity 100 ISO is used. According to the laboratory [13] this range reaches approximately 11 EV, according to [14] approximately 8 EV. The smaller (8 EV), more restrictive, value of the range definition guarantees, in our opinion, the linearity of processing in better way. However after some experiments we noticed that extending this smaller range about 1 EV towards the high luminance for including light sources does not change the working conditions and it fits in the range proposed in laboratory [13]. Taking into account such assumption we analysed the whole range of luminance available in series of HDR images (Fig. 3). This way we assumed the range of 13 EV as the result of analysis, we calculated changes of TV and proposed the algorithm for HDRI preparation.

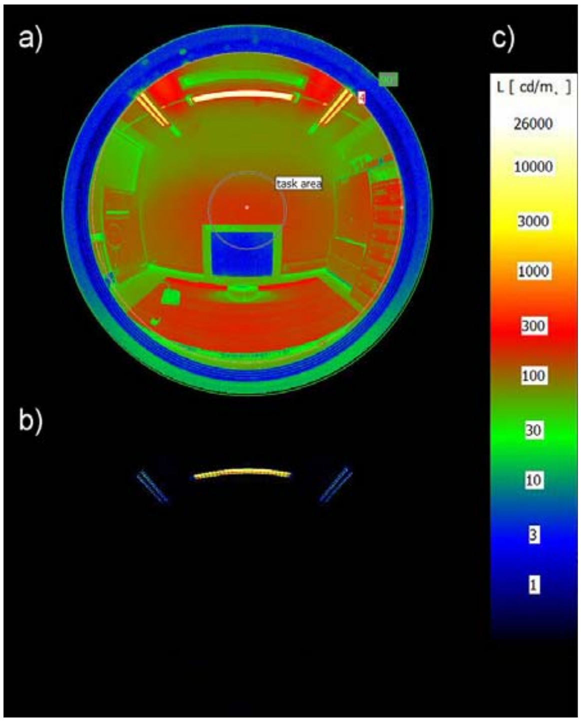

Fig. 4. Windows from the LMK system software. a) view from circular fisheye lens, b) masked places of highest luminance, c) luminance scale. Using proposed algorithm, starting shutter speed was set in proper way – the masked sources of light have correct calculated luminance (presented in scale of software). The value of UGR has been calculated in correct way.

The algorithm

1. Place a camera on a tripod and adjust position – looking through the viewfinder select proper part of space (working environment with light sources). It should be certainly done after visual analysis of the environment.
2. Set proper parameters of a camera according to documentation of LMK system (100 ISO, AV mode, F8.0). Set display format where overexposed highlights blink as a highlight alert.
3. Measure (with luminance meter) the luminance of the bright elements in the environment that correspond to the brightest places of the taken picture (from the observer position). Most often these elements are lighting sources (the sources of glare). Determine $LMAX$ – the highest value of luminance and the place where it appears.
4. Determine the $TLMIN$ time – the minimal time which allows taking places with highest luminance in correctly exposed picture.

4.1 Take several test pictures in AEB mode. Using camera metering system, obtain the standard exposure and than decrease it about 2 *EV* (reduce shutter speed 4 times).

4.2 Select one picture where overexposed highlights blink (as a highlight alert) in places of light sources and additionally it is a picture with shortest shutter speed. Assume this shutter speed as a *TLMIN* time.

5. Determine *THDR* as: *THDR* = *TLMIN* – 3 *EV*.
6. Set *THDR* as a standard time for AEB mode. Take series of 3 pictures in AEB mode. Import these pictures to LMK software and create HDR file in pf format. Using this file determine *LPF* – the highest value of luminance, registered in LMK software.
7. Correct the *THDR* time with the highest resolution allowed by camera (1/3 *EV*).
   If *LPF* corresponds to *LMAX* go to step 8.
   If *LPF* < *LMAX* decrease *THDR* and repeat step 6.
   If *LPF* > *LMAX* increase *THDR* and repeat step 6.
8. Set *THDR* as a standard time for AEB mode. Take series of 3 pictures (using AEB mode) for glare assessment. Import these pictures to LMK software and calculate *UGR*.

The first two steps in this algorithm certainly do not take a part in determining proper *TV* but are required generally for taking proper pictures.

We applied elaborated algorithm in the same working environment (shown in Figure 2.). It allowed obtaining exposed HDR image correctly (Fig.3.) and determining proper value of *UGR* in LMK software.

Summary

The effective algorithm of preparing the HDR images for *UGR* calculation and discomfort glare assessment has been presented.

We conducted the analysis how the different parameters of exposure influence the properties of series of HDR photographs. We took into consideration properties of camera's sensor and dependencies between parameters that describe exposure. The main principle was assumed, that the maximum dynamic range available in the LMK photometer should be used. Our analysis allows calculating the *TV* (shutter speed) that set the border value of the luminance range as corresponding to the maximum value of the light sources luminance.

Proposed algorithm allows using the capabilities of the digital camera sensor and minimizing the *UGR* measurement errors. Conducted experiments showed correctness of the introduced solution.

*This paper has been based on the results of a research task carried out within the scope of the second stage of the National Programme "Improvement of safety and working conditions" partly supported in 2011--2013 --- within the scope of research and development --- by the Ministry of Science and Higher Education/*National Centre for Research and Development*. The Central Institute for Labour Protection -- National Research Institute is the Programme's main co-ordinator.*

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