HDR IMAGES FOR GLARE EVALUATION: COMPARISON BETWEEN DSLR CAMERAS, AN ABSOLUTE CALIBRATED LUMINANCE CAMERA AND A SPOT LUMINANCE METER

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Abstract

User calibrated digital single-lens reflex (DSLR) cameras are being used in visual comfort and especially for glare evaluations as affordable alternatives to high-end luminance cameras calibrated by the manufacturer itself. While the typical way for a user calibrated camera is the application of an *automatic* calibration algorithm, manufacturers, on the other hand, tend to rely on a calibration process for their cameras based on measurements performed for each exposure setting (*absolute* calibration). This paper investigates the accuracy of luminance maps derived from HDR images captured with auto-calibrated DSLR cameras. More specifically, the aim of this study is to compare the luminance values obtained with an auto-calibrated DSLR camera for different light scenarios on one hand to a commercially available camera (that benefited from an absolute calibration) and on the other hand to a handheld luminance meter, considered as the reference. It was found that there are only small differences when luminance values estimated with auto-calibrated DSLR cameras are compared with those obtained for the commercially calibrated camera for low to mid-range luminance values (50 – 5000 cd/m^2). However, for higher luminance values (>5000 cd/m^2), HDR images from the auto-calibrated camera show differences of up to 20 % when compared to the manufacturer calibrated camera, which could be problematic for glare investigations. More studies specifically focusing on high luminances are thus needed, so as to determine more conclusively whether certain limitations should apply to the use of automatically calibrated DSLR cameras for glare evaluations.

Keywords: Photometry, HDR imaging, Camera calibration

1 Introduction

When appraising visual discomfort in spaces, it is common to evaluate glare. This is typically done by evaluating high dynamic range (HDR) images with different glare prediction models such as Daylight Glare Probability (DGP) or Daylight Glare Index (DGI). However, in order to get reliable results from these models, the HDR images have to be accurate, especially in the high luminance range. It is therefore necessary to use calibrated cameras that can be trusted to provide correct luminance values in glare studies.

Manufacturer-calibrated luminance cameras that promise luminance accuracy of less that ± 5 % exist, but these are quite expensive. As an alternative, it is possible to use a normal digital single-lens reflex (DSLR) camera to produce HDR images. These cameras are somewhat inexpensive, making them an easy choice for glare or luminance studies. However, DSLR cameras have to be calibrated before they can produce HDR images with dependable luminance outputs. Studies have shown that these have an accuracy between 10 and 20 % when compared to handheld luminance meters (Anaokar and Moeck, 2005; Inanici, 2006).

A normal low dynamic range (LDR) camera image typically covers a luminance range of 1:100 whereas a scene potentially can cover 1:10^9. In a nutshell, to generate a HDR image, several LDR images are merged into a single image, so as to cover a wider range of luminance. Different tools using automatic algorithms such as hdrgen have been developed for this purpose. These algorithms estimate the camera response curve to match image sensor values to the luminance of the scene. The camera response curve is the relationship between the light that falls on the image sensor and the outputted pixel value of the HDR image. The automated algorithm is used to generate an estimate of the response curve, based on the series of LDR images. It is common practice to create one response curve from a scene with both dark and bright areas and use this curve in future scenes. It is also common to perform an adjustment of the image based on a luminance meter measurement after applying the automated calibration algorithm (Jacobs, 2007; Reinhard et al., 2010; Ward, 2017).

An absolute calibration of a camera relies on more detailed knowledge about how the camera records light. An absolute calibrated camera also merges several LDR images together, although with response curves, which were derived in advance during a calibration process. For this kind of calibration for each aperture and exposure combination a measurement of luminance is conducted. This calibration method is often used in commercially available luminance cameras. (Coutelier and Dumortier, 2002; Krawczyk et al., 2005; Reinhard et al., 2010).

The purpose of this paper is to investigate if using an automatic calibration algorithm results in HDR images with luminance values that are comparable with those obtained with a commercially available camera, benefiting from an absolute calibration. As handheld luminance meters, such as the Konica Minolta, are often used as references in glare studies, the cameras will also be compared to such an instrument. As a further control of luminance images, illuminance will be calculated in this study by integrating luminance values across the images and comparing the integrated value to the measured illuminance at the camera position.

2 Methodology

Two DSLR cameras are calibrated so that they can be used for HDR imaging with the automatic calibration algorithm. The calibration of the DSLR cameras also includes image projection correction and vignetting* correction. Thereafter, luminance values obtained with these DSLR cameras in different light scenarios are compared with measurements from an absolute calibrated camera and a luminance meter. Illuminance at the cameras' position is also measured and compared to the estimated illuminance based on the luminance maps.

2.1 DSLR Calibration

The calibration of the two DSLR cameras followed guidelines outlined in photometric literature. (Anaokar and Moeck, 2005; Bellia et al., 2003; Inanici, 2006; Jacobs, 2007; Jacobs and Wilson, 2007; Reinhard et al., 2010). First, it was necessary to derive a response curve for the camera, as the curve is important for the automatic calibration algorithm to create HDR's. These curves vary between cameras, even for the same manufacturer and model, and have to be derived for each individual camera. The second step is to correct, if necessary, for the projection method of the lens. The third step is to correct for vignetting by measuring the light drop-off from the center to the edge of the lens. Finally, it is normal to carry out a calibration of the images by adjusting the pixel value of a target in the scene. This can be done by measuring the target with a luminance meter and adjusting the HDR image so that the image and measured luminance values match.

Two Canon 70D cameras with Sigma 4.5mm fisheye lenses were calibrated for this study. After some initial testing, and in line with the aforementioned literature, the following general settings were applied to both DSLR cameras. The white balance of the cameras was set to daylight, ISO speed (light sensibility of sensor) to 100, image quality to large .jpeg, picture style to standard, auto contrast and image brightness correction to off and colour space to sRGB. Auto focus was also turned off and the focus was set to infinity. Control of the cameras was done with the free program qDslrDashboard and its "Sky stack" function. This enables the user to program a series of different shutter speeds to be shot sequentially, when the image release is activated (qDslrDashboard, 2017).

In this study, the automatic calibration algorithm used to merge series of LDR's into HDR's is Greg Wards *hdrgen*. It was called with the command "hdrgen LDR_image_series_*.jpg –o HDR_name.hdr –r response_curve.rsp –a –e –f –g –x". With this selection of qualifiers, it is possible to use the generated response curve for the appropriate aperture. The program also removes over and underexposed images while removing flare and ghosts (Ward, 2017).

* Light drop-off at the edges of an image due to the optical properties of the lens used.

2.2 Response curve

The two DSLR cameras were placed in a room with large windows, on a clear day with some sun penetration into the room, but without the sun in the field of view of the cameras. The scene contained desks, chairs, a view to the outside and there were large white, grey and black areas as well, see figure 1. This was done to ensure dark and bright areas across the scene. A series of 13 low dynamic range images, with shutter speeds ranging from 1/8000 s to 5 s, were made for each aperture setting with both cameras. These images were combined to HDR images with the “hdrgen” program although without calling a file name for the “-r” qualifier. This makes the program generate the equations for the response curves in addition to the HDR images. The files containing the response equations for each aperture were saved so that they could be used for future images. Figure 2 show the red channel response curves from camera 1 for all its aperture sizes. As can be seen the curves differ with aperture size.

Figure 2: The scene used for creating the response curves.

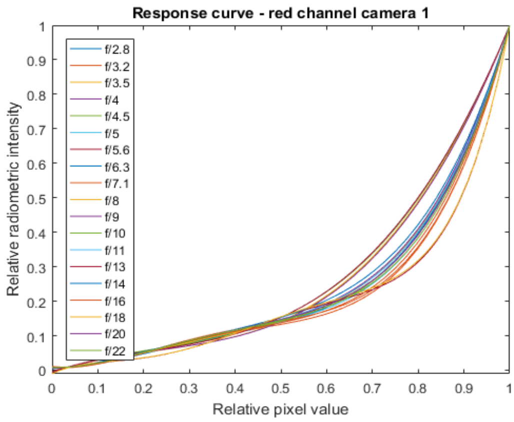

Figure 1: The red channel response curves for camera 1 for all the apertures.

2.3 Reprojecting

The lenses used (SIGMA 4.5mm, fisheye) has an equisolid-angle distortion. This distortion is not supported by any of the glare evaluation-tools (like Evalglare (Wienold et al., 2004)). Therefore the images have to be reprojected to an equidistant distortion. This was done by piping the images of through the following Radiance-command: “pcomb –f fisheye_corr.cal –o”. The fisheye_corr.cal file is a script file that have been created to correct fisheye projection (Ward, 2016). The default setting of the script is to correct an equisolid projected image to an equidistant projection. Before the images were reprojected, they were cut into a square that just fit the circular image. The header of the images were also corrected afterwards to ensure that evalglare could process the images. The “view” entry in the header was set to “-vta –vh 180 –vv 180” with no tabulator in front and the exposure entry was removed.

2.4 Vignetting calibration

To identify the vignetting of the lenses the DSLR cameras were mounted on a tripod so that they faced a light source. The source was a 400W halogen lamp placed behind a diffuser screen that had a cover with a 5 cm diameter aperture in it, see figure 3. The cameras could rotate horizontally around their nodal point, so that the light source was visible from one edge of the lens to the other edge. An HDR image was generated of the light source at 10° increments from 0° to 180° as well as 5°, 15°, 25°, 155°, 165° and 175°. This was done for both cameras and for all aperture settings. The luminance of the center of the light source was extracted of each image and for each increment and normalised to the center values, derived from the 0° image. Figure 4 shows a selection of different vignetting curves of different aperture sizes from the red channel of camera 1.

Figure 3: The vignetting setup with the camera pointing at the source.

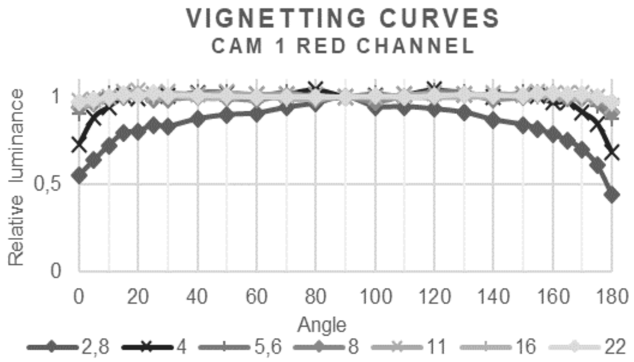

Figure 4: A selection of vignetting curves from different apertures for the red channel of camera 1.

As it is reasonable to assume that the lenses are symmetrical, vignetting curves were created by averaging and plotting the 0° and the 180° luminance values, the 5° and 175° luminance values and so on. 6th order polynomial curves were fitted to the resulting curves and the formulas for these were incorporated into a .cal file. These .cal files could then be applied to the HDR images to correct for vignetting by piping the image through the following Radiance function "pcomb –f vignetting_file.cal –o". In this study, it was found that the vignetting was similar for both lenses and that it was most pronounced at lower aperture sizes, mainly between f/2.8 and f/7.1. Above those f/stops, the curves show very small luminance reductions at the border and therefore vignetting has less of an impact, see also figure 4. This indicates, that with this lens/camera combination it is advisable to use f/stops of above f/7.1 to minimise the risk of vignetting.

2.5 Luminance calibration

With the automatic calibration algorithm method it is normal to perform a final luminance adjustment of the images. A target in the scene is measured with a luminance meter and the ratio between the measurement and the image is used as an adjustment factor that is applied to all pixels in the image. In this study, the adjustment factors for the DSLR cameras were calculated based on the manufacturer-calibrated camera and from the second highest luminance value out of five targets in each scene. The images were adjusted with the following Radiance command: "pcomb –f factor input_image.hdr –o > corrected_image.hdr". The average factor was 1,15 and 1,19 for camera 1 and 2 respectively.

3 Measurement setup

The cameras used were two Canon DSLR cameras and a manufacturer absolute calibrated LMK 98-4 color camera from TechnoTeam (TechnoTeam, 2017). The manufacturer guarantees an accuracy of 4,7 %. The cameras were mounted on the same tri-pod and an illuminance sensor (LMT Pocket Lux) was mounted on top of one of the cameras as shown in figure 5. Luminance measurements with a handheld Konica Minolta LS110 luminance meter was done with the meter as close as possible to the cameras. An aperture size of f/11, which had little vignetting, was used for all DSLR camera images. One of the DSLR cameras and the LMK camera were controlled with a laptop while the other DLSR camera was controlled with a smartphone through the cameras on-board WIFI function. Illuminance and luminance values from the meters were noted down during the image caption sequence.

Figure 5: The instrument setup used in the study.

Five different scenes were shot using the different cameras and can be seen in figure 6. Scene 1 (top left) was shot in an empty room and with the cameras facing the window. This scene compares luminances up of to 300 cd/m². Scene 2 (top middle) was shot on a clear day in a corner office with windows at the side and behind the cameras. This scene compares luminances of up to 750 cd/m². Scene 3 (top right) was shot in a two-person office with the cameras facing the window, overlooking both workstations. This scene compares luminances up to around 8.000 cd/m². Scene 4 (bottom left) was shot at a workstation with a view parallel to the window. This scene compares luminances of up to 11.000 cd/m². Scene 5 (bottom right) was shot outside with the cameras in shadow but facing a bright scene. This scene compares luminances of up to around 12.000 cd/m².

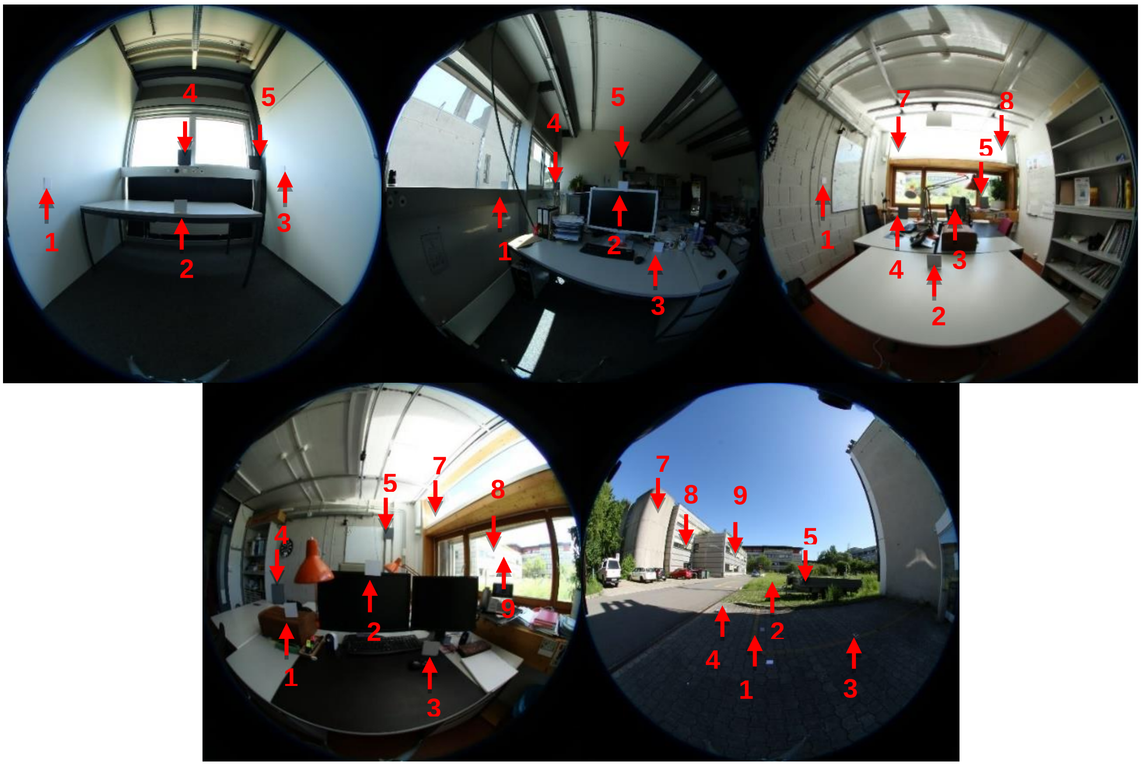

Figure 6: The five different scenes with the compared areas indicated. In the top scene 1, 2 and 3 and in the bottom scene 4 and 5.

Five different targets were set up in the scenes. Three were cardboard squares covered with ordinary white printer paper. The other two targets were JJC Colour Balance Cards, grey cards, with a reflectance of 18 %. The white paper cards were placed in the foreground and at the sides and front of the cameras, while the larger grey cards were placed further back and at the sides of the cameras. Their placements in the different scenes are indicated as 1 to 5 in figure 6. Different positions of the shading systems were also deployed; such as no shading (A), shading half way down (B), all the way down and with vertical slat position with venetian blinds (C) and with the shadings down but with the artificial light on (D). In scene 1 and 2, there were venetian blinds and when they were in the fully down position the slats were in the vertical position. In scene 3 and 4, the blinds were fabric and scene 5 was taken outside.

The center luminance values of the targets were retrieved from the DSLR camera images with the Radiance “ximage” program. For the LMK camera the accompanying Labsoft software were used to derive the luminance values from the targets. Evalglare was used to calculate vertical illuminance of all the images. A simple comparison between the cameras and the luminance meter were carried out by comparing target luminance values. The measured illuminance values were also compared with the calculated value from the HDR images. Measurements with the Konica luminance meter were not done outside the targets. However, high luminance areas in some scenarios were compared between the LMK and DSLR cameras.

4 Results: Instrument comparison

4.1 Konica Minolta luminance meter and LMK luminance camera comparison

Figure 7 show all luminance measurements with the Konica Minolta luminance meter and the LMK luminance camera sorted from smallest to largest. The bars show the percentage difference between the instruments and follow the right hand axis. The two instruments seem to perform similarly and the lines follow each other. Closer comparison between the two instruments showed that there in fact were small differences between the two instruments. The differences were generally below 10 %, in some cases between 10 and 20 % and only in some cases higher; as much as 42 %. However, the larger differences occur when measuring low luminances where a small difference have a large impact on the percentage difference.

Looking at absolute differences the general tendency was for the difference to be below 20 cd/m² and only in some cases higher with the maximum difference being 60 cd/m².

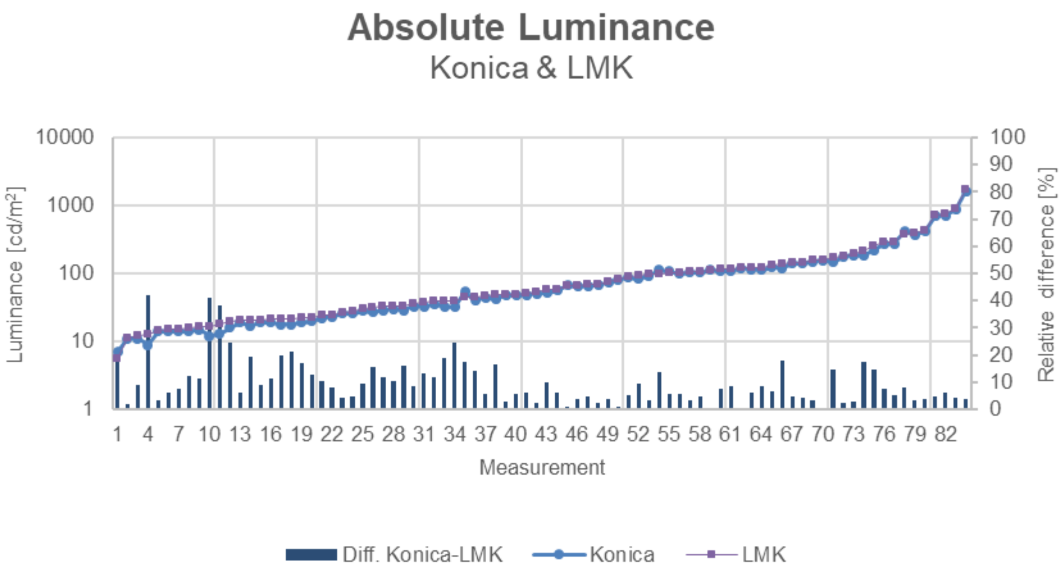

Figure 7: Luminance values measured with the Konica Minolta and LMK luminance camera. The bars show percentage difference and follow the right-hand axis.

Figure 8 shows the measured illuminances from the LMT meter and the calculated illuminance values from the LMK camera images. Bars show the percentage difference between the instruments and follow the right hand axis. Comparing illuminances from the two instruments showed that the differences were generally below 15 % and often less than 5 %. However, there were some instances where the difference was larger than 15 %, but these typically occurred in the low luminance range where a small absolute difference have a larger impact on percentage difference. The maximum absolute difference was 185 lux, but differences were in general less than 100 lux.

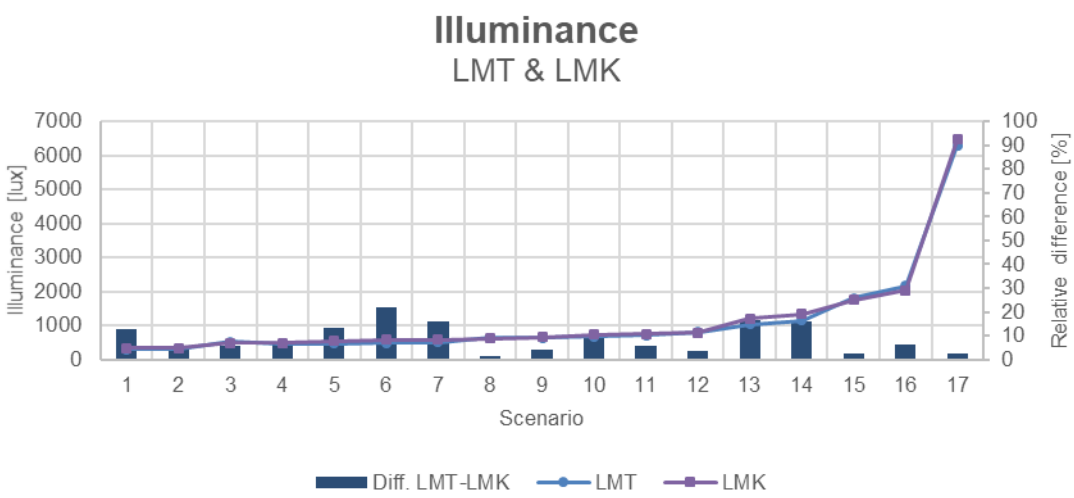

Figure 8: Illuminance values measured with the LMT meter and calculated from the LMK camera. The bars show percentage difference and follow the right-hand axis.

4.2 Konica Minolta luminance meter and DSLR camera comparison

Figure 9 show all luminance measurements with the Konica Minolta luminance meter and both DSLR camera with bars showing their percentage difference. Please note that two measurements reach over the scale; these being 165 % and 197 %. Comparing the DSLR cameras to the Konica Minolta luminance meter shows that there are differences between the instruments that generally are below 10 %. Larger differences are more frequent than between the LMK and the Konica. Looking at the absolute differences these were generally below 30 cd/m² and the largest absolute difference was 84 cd/m² for camera 1 and 225 cd/m² for camera 2.

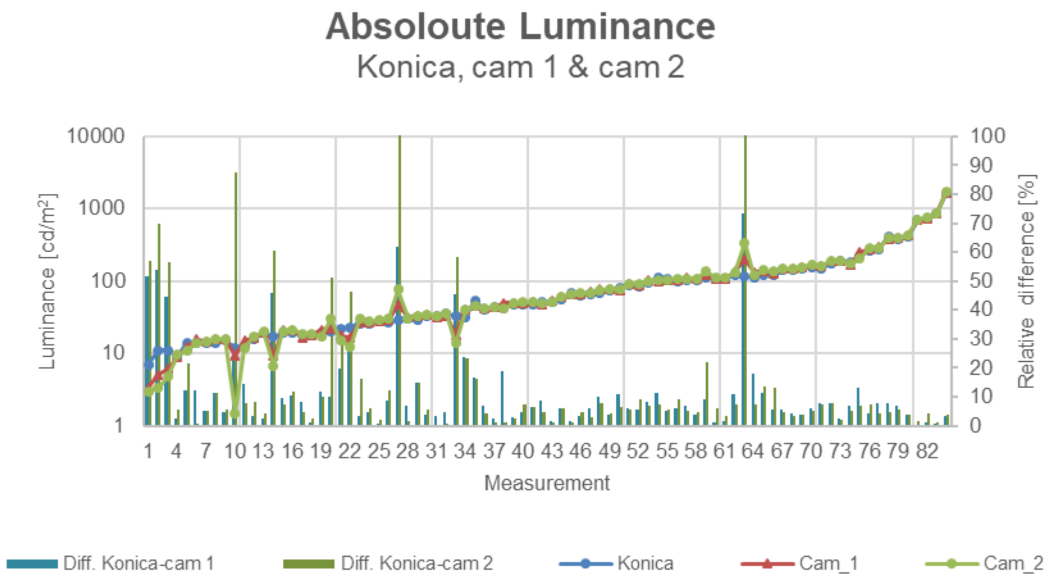

Figure 9: Luminance values measured with the Konica Minolta and DSLR cameras. The bars show percentage difference and follow the right-hand axis.

Figure 10 shows the measured illuminances from the LMT meter and the calculated illuminance values from the DSLR camera images with bars showing percentage difference on the right hand axis. Comparing the illuminances from the three instruments showed that the differences were generally below 20 % and in one case 172 % (out the scale in figure 10). The reason for this large difference could be measurement error with light scatter that hit only part of the camera setup. The maximum absolute illuminance difference was 780 lux for camera 1 and 728 for camera 2. The differences were generally larger in the higher illuminance scenarios. The illuminance differences were larger between the Konica and the DSLR cameras than they were between the Konica and the LMT camera.

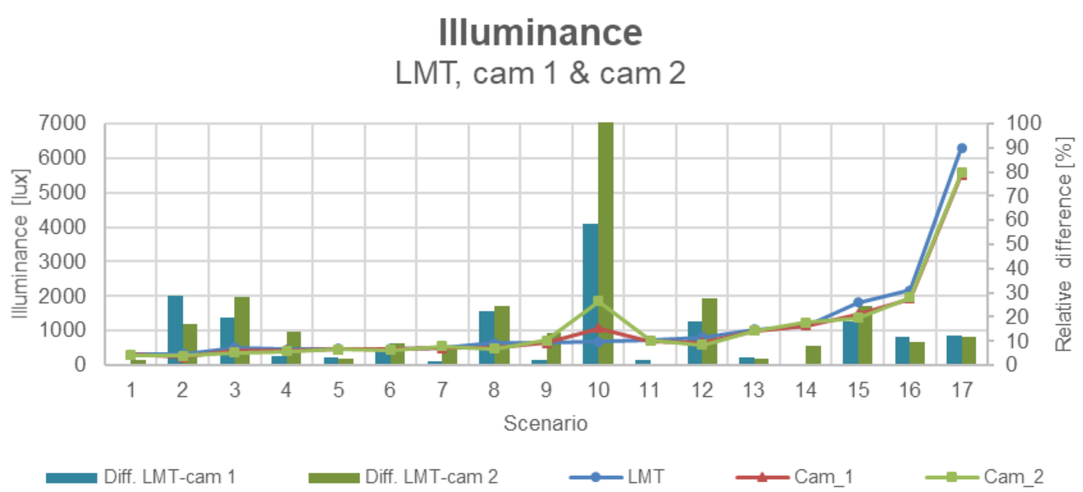

Figure 10: Illuminance values measured with the LMT meter and calculated from the DSLR cameras. The bars show percentage difference and follow the right-hand axis.

4.3 LMK luminance camera and DSLR camera comparison

Figure 11 show the sorted luminance measurements with the LMK luminance camera and both DSLR cameras, with bars showing percentage difference on the secondary y-axis. Please note that two measurements reach over the scale; these being 137 % and 180 %. With the images, it was possible to identify higher luminance areas and compare them. However, these areas did not have a target and thus no luminance measurement from the Konica Minolta. The larger percentage difference are again at the low end of the luminance range.

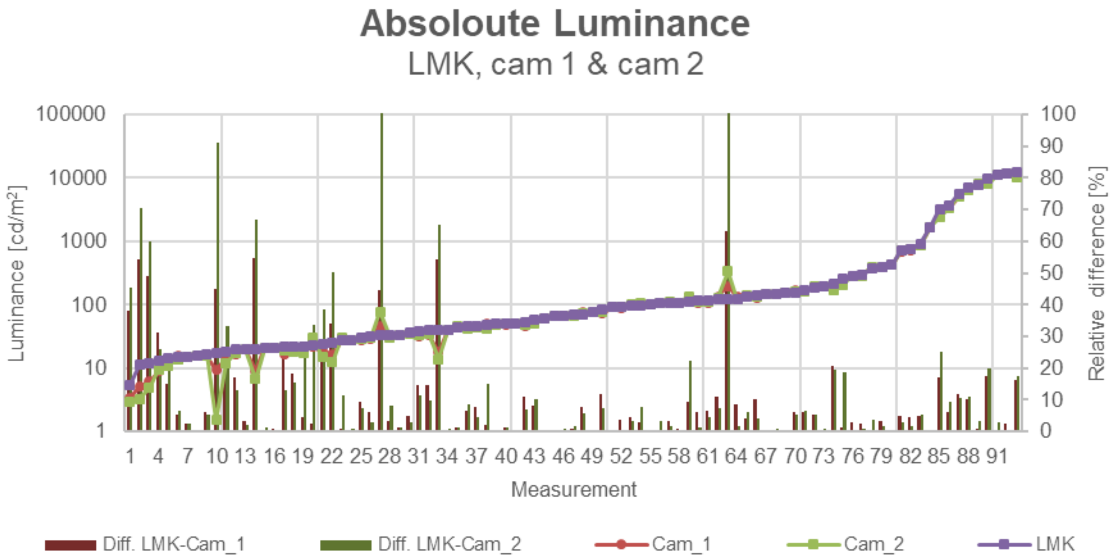

Figure 11: Luminance values measured with the LMK and DSLR cameras. The bars show percentage difference and follow the right-hand axis.

The luminance camera measurements of the higher luminance range in this study are shown in table 1. The first columns show the measured values while the last 2 columns show the differences with those over 10 % highlighted in bold. As can be seen, there are some instances where there are large differences while in others the differences are relatively small. The reason for this different behaviour is unclear, especially since the scenes were not so much different in the light distribution and intensity. However, there is a tendency, that for the larger deviations the values are underestimated, never overestimated. This is concerning, since an avoidance of systematic errors and the accuracy in the higher luminance range are important boundary conditions for the measurements in glare studies. Therefore, more studies are needed to investigate this discrepancy.

Table 1: The 8 highest luminances. The first columns show the measured luminance values. The last 2 columns show the absolute difference, with differences over 10 % in bold.

Scenario	Cam_1	Cam_2	LMK	Diff. LMK-Cam_1	Diff. LMK-Cam_2
Scene_3_Lum_7	3459,1	3339,7	3678,8	219,7	339,1
Scene_4_Lum_8	4994,5	5070,6	5659,9	**665,4**	**589,3**
Scene_4_Lum_9	6422,7	6374,7	7155,3	**732,6**	**780,6**
Scene_3_Lum_8	7748	7920,1	7670,6	-77,4	-249,5
Scene_5_Lum_8	8214,3	7952,5	9947,9	**1733,6**	**1995,4**
Scene_4_Lum_7	11319	11008	11350,2	31,2	342,2
Scene_5_Lum_9	11550,6	11912,8	11835,6	285	-77,2
Scene_5_Lum_7	10470,6	10278,3	12478,5	**2007,9**	**2200,2**

All table values in cd/m2.

Figure 12 shows the calculated illuminances from the LMK and DSLR camera images with bars showing percentage difference on the right hand axis. The graph shows that the differences were generally below 20 % and in one case 149 % (out the scale in figure 12). The reason for this large difference could be measurement error with light scatter that hit only part of the camera setup. The illuminance differences were generally larger than between the cameras and the LMT illuminance meter.

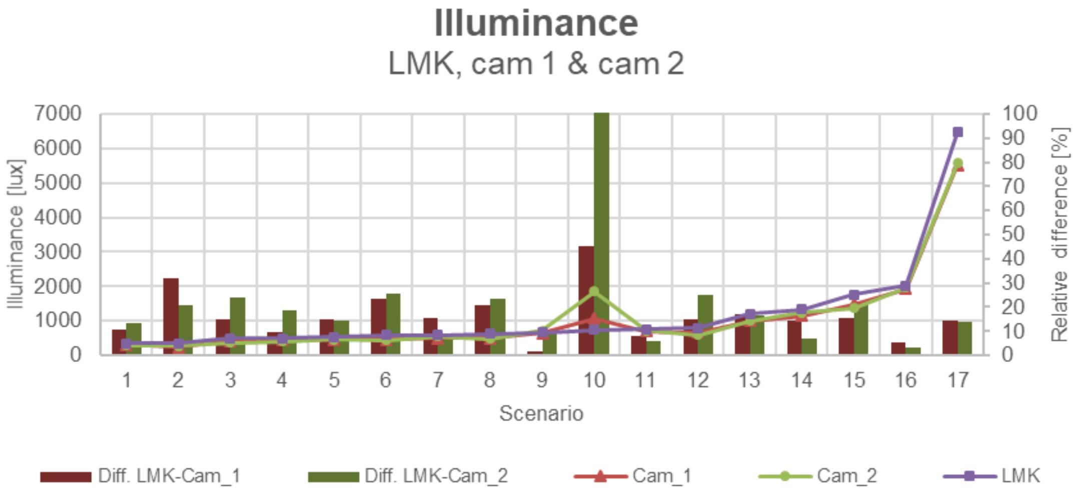

Figure 12: Illuminance values calculated from the LMK and DSLR cameras. The bars show percentage difference and follow the right-hand axis.

5 Result synthesis

When comparing the handheld luminance meter to the manufacturer calibrated luminance camera, they generally had similar luminance values, which was expected. It is reasonable to assume that the manufacturer calibrated luminance camera is accurate enough for glare evaluations.

Comparing the two DSLR cameras to each other it seems that they perform similarly although camera 1 seems to have less extreme differences. Both DSLR cameras seem to have trouble resolving luminances below 50 cd/m^2 accurately when compared to the Konica Minolta luminance meter and the LMK luminance camera. However, this is not a problem if the DSLR cameras are intended for glare evaluation, as this should not have a significant influence on glare ratings. For mid-range luminances (100 cd/m^2 - 5000 cd/m^2), the differences between the LMK and the DSLR camera were of the same order of magnitude as the differences between the LMK luminance camera and the Konica luminance meter. It is expected that some of the differences could be due to measurement error, as it was hard to place the handheld meter close to the cameras.

For the higher luminance values, there are some differences between the LMK camera and the DSLR cameras; in some cases a difference of up to 20 %, although there is no coherent trend, except the fact, that these larger deviations are entirely underestimations. This is concerning as differences in this range could lead to incorrect glare estimations.

When looking at the vertical illuminance the difference between the LMT illuminance meter and the values calculated from the LMK camera were generally below 10 % and often below 5 % and only exceptionally above 20 %. Some of the difference could be explained by measurement error as the sensor was placed a little behind the camera lenses and to the side (see figure 5). There were larger differences between the illuminance values calculated from the DSLR camera images and the values calculated from the LMK images. These differences were generally between 10 and 25 %. The same is true for the differences between the LMT illuminance meter and the DSLR cameras. This is an indicator of the inaccuracy of the DSLR cameras, as the illuminance discrepancy probably is due to the inaccuracies in luminance values.

6 Conclusion and outlook

Two Canon 70D DSLR cameras with Sigma 4.5mm fisheye lenses were setup so that an automatic algorithm could be used to calibrate them for luminance measurements. Luminance maps of different light scenes taken with the DSLR cameras where compared with measurements taken with a manufacturer absolute calibrated LMK luminance camera. Small differences were found for low to mid-range luminance values (50 – 5000 cd/m^2). These were of the same order of magnitude as differences between the LMK and a Konica luminance meter and should not significantly influence glare estimation results. However, it seems that the DSLR cameras had larger deviations (up to 20 %) when resolving high luminance values (> 5000 cd/m^2). These deviations were in all cases underestimations. This is problematic, as high luminance values are important in glare evaluations. More investigation is needed, to elaborate why this discrepancy exists. Furthermore, it seems that vertical illuminance values, calculated based on images from the DSLR, cameras had a systematic underestimation between 10 and 20 % when compared to the LMK camera and the LMT illuminance measurements. This is most likely due to the differences in the high luminance range.

More studies should to be done in bright scenes, so that the accuracy of DSLR cameras in high luminance scenarios can be investigated in more detail. It also remains to investigate if and how DSLR cameras can resolve very high luminances – for example scenes where the sun is directly in the field of view of the camera. For the DSLR cameras to handle such scenes it is expected that they will need a filter to minimize the risk of the image sensor burning out. As an outcome from this study, it is recommend that illuminance and at least 2 luminance targets, in the high and low range, are measured in order to check/correct the image when using user-calibrated DSLR cameras as luminance instruments.

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