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About Glare And Luminance Measurements

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Abstract

Glare is an unwanted scattering of light occurring upon its propagation through optical media, whose scarcely predictable, scene-dependent effects are potentially disrupting in terms of accurate scene acquisition.

This work starts from the idea of assessing the magnitude of glare in low dynamic range monitor layers during visualization. According to common practice, monitor dynamic ranges are computed as ratios of maximum to minimum luminance values separately acquired on full-screen black and white images. Avoiding the coexistence in the same image of maximum and minimum luminance, this method does not consider the effect of possible intra-layer glare.

To measure possible intra-layer glare in a monitor, we have displayed images made up with black and white patterns of different sizes. Measuring these different patterns, we detected changes in the luminance of the black regions. At first we explained data as a glare effect. Measuring more carefully each regions through a masking cardboard with a hole, these differences were no more there. It was just glare, not from the monitor layers, but from the lens of the measuring instrument.

To further investigate the issue, another setup was arranged whereby two color checkers were stationed behind a dimmable light source aiming away from them both, and directly into the luminance meter. We found that despite light being unable to fall directly on the color checkers, an increase of radiant power was paralleled by an upward drift in luminance values for all examined spots, more so for those lying the closest to a prominent lens flare within the device viewing field.

These combined findings show us that no matter the accuracy of the measuring device, luminance information can neither be measured nor displayed correctly in the presence of glare in the instrument.

Introduction

In order to compute the dynamic range of a scene, luminance values need to be measured with optical devices composed of a lens system. Lenses are meant to let light beams through, and by means of a combination of reflection and refraction, focus them on sensors or photosensitive substrates. All optical devices, notwithstanding their level of craftsmanship, are fraught with aberrations, some of them subtle, some others severe. This paper aims at describing the effects of glare, an unwanted spread of light within optical media, whose interference greatly alters dynamic ranges and ultimately image perception. As pointed out by previous works [1][2][3][4], the higher the dynamic range of a scene, the higher the loss of contrast in the acquired image. This issue is made absolutely substantial by the vast popularity High Dynamic Range (HDR) imaging has been gaining within the last twenty years.

Light scattering happens whenever beams stray from their predicted rectilinear path, as a consequence of non-uniformities affecting the medium through which they travel [5]. Depending on the quantity and spatial arrangement of the scattering loci, different non-ideal luminance profiles manifest, and estimates of image degradation may not be inferred with sufficient precision. Glare shows indeed markedly scene-dependent properties. It is strongly influenced by the spatial features of the scene acquired, in a way that tends to be hardly predictable and cause an unwanted decrease of contrast, particularly in those regions of the image where luminance is lower [3].

The initial intent of this work was an assessment of intra-layer glare effects in monitors. Usually, when monitor dynamic ranges are evaluated, they are computed as ratios of luminance produced by a full-screen white to that of a full-screen black. These are two distinct cases of zero dynamic range scenes that display no contrast and thus no glare. On the contrary, real images are based on contrast and are subject to spatially varying glare.

Measuring displays

Checkerboard test

The first test aimed at evaluating intra-layer glare on a dual-layer HDR black and white monitor, a 19 inches 1280 × 1024 pixels prototype by Barco, and on a 24 inches 1920 × 1200 pixels LDR monitor by EIZO.

As test images, we prepared image sets of maximum and minimum luminance checkerboards of patch size from 150 mm down to 10 mm, with a decreasing 10 mm step in the 150-100 mm range and a decreasing 5 mm step in the 100-10 mm range. Although eventually side length had to be provided in pixels upon image composition, millimeters were chosen over pixels in order to secure consistency and ease of comparison between the monitors.

Given a diagonal D inches long and a resolution of d_x by d_y pixels, any given length in millimeters $l_{(mm)}$ can be easily turned into its pixels counterpart $l_{(pix)}$ by (1):

$$l_{(pix)} = l_{(mm)} \frac{\sqrt{d_x^2 + d_y^2}}{25.4D} \quad (1)$$

the rightmost ratio being the reciprocal of the dot pitch. Due to squares not being full integer fractions of monitor dimensions, rectangular residues appeared along both the vertical and the horizontal. Symmetric offsets were then introduced in order to have central squares—on which all measurements were taken according to [6]—reposition tightly around the monitor center.

Finally, in order to accommodate the dual layer HDR monitor with the required image format, all checkerboards there to be displayed were extended along the horizontal dimension by specular replication along the vertical border. This operation provides the monitor the desired 2560 × 1024 pixels image, half of which folds back onto itself doubling the foremost layer onto the posterior layer.

Luminance measurements were taken in a dark room with a Konica Minolta Spotmeter F. A plot is reported showing preliminary assessments of intra-layer monitor glare for minimum and maximum luminance checkerboards on both LDR and HDR monitors (**figure 1**). For both of them, base luminance values of the black patch under scrutiny show a slow but continuous overall increase, which comes to a steep upward drift upon approaching patches 30 mm in size. Near-convergence of black and white patches luminance is reached by the end of the shrinking sequence, where patches were too small for the device to operate a clear distinction between the two. For this gradual increase, glare emanating from white patches was deemed responsible: the closer the luminance gradient to the measured area on central black patches, the more prominent the effect of glare.

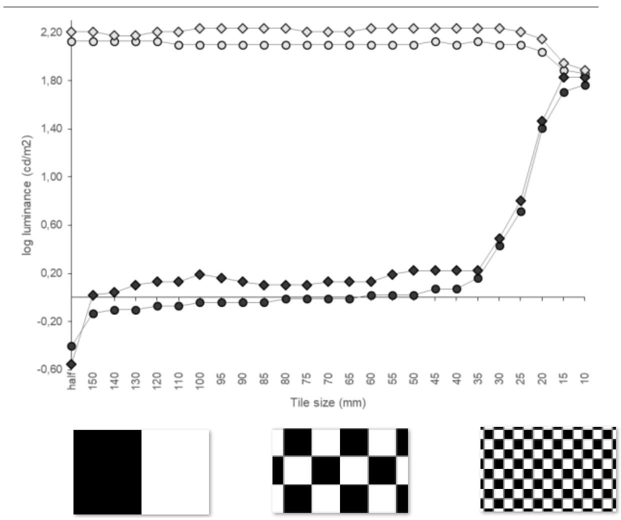

Figure 1. Trends of base log luminance values of checkerboard white patches (light grey, upper series) and black patches (dark grey, lower series) displayed on an LDR monitor (circle markers) and HDR monitor (diamond markers). Three examples of checkerboard are also shown. From left to right "half", "85mm", an intermediate step, and "30mm", where a steeper gradient is reached, eventually leading to patterns where clear distinction among white and black patches by the spotmeter began to fail.

Further measurements

In order to corroborate this hypothesis, another instrumental setup was arranged. Luminance measurements were taken on a 19 inches 1440 × 900 pixels LDR monitor by DELL (E1910c), for which no particular pre-settings were arranged other than maxing out both its brightness and contrast beforehand. This time, once the desired image set was primed for displaying, the whole monitor was entirely covered by means of a tightly fitting, opaque, nearly-lambertian cardboard mask, with a small square slit in the middle that let a small portion of the underlying image pass through (**figure 2**). Slit and mask edges were framed in black tape, so to avoid light leakages and ensure monitor adherence at the same time.

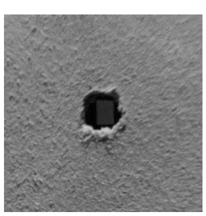

Figure 2. Mask slit bordered by black tape. The minimum luminance image patch shows through in the middle.

All measurements were taken with a LMT Pocket Lux2 illuminance meter. The device was securely stationed on a tripod set 0.60 m away from the monitor, an optimal viewing distance for a hypothetical human viewer under the specified resolution and diagonal length (**figure 3**). Instrument focus was adjusted accordingly, and the active measuring spot was narrowed in such a way as to only encompass a few image pixels, discarding interferences from the black tape set around the mask slit, and of course from the mask itself.

The test environment was a dark room normally used for lighting devices goniophotometry, a corridor fully covered in black matte tapestries. Ambient lights were switched off a few minutes in advance, so that sensors would settle and adjust accordingly. No other light sources were switched on during the measurements.

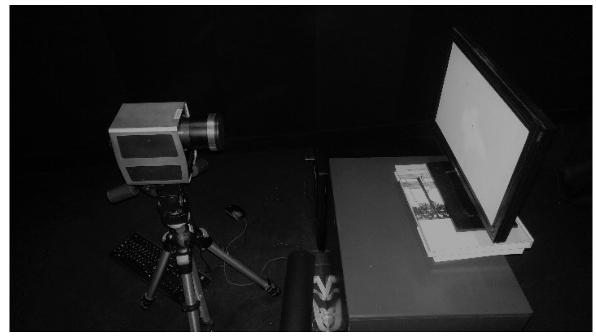

Figure 3. First experimental setup. The illuminance meter is set 0.60 m away from the monitor, and focuses on the displayed image patch let through by the cardboard mask. Images within the image set were displayed in an orderly fashion, from biggest to smallest minimum luminance squares. All lights were switched off for the whole duration of the experiment.

In this case, the test image was a single square patch whose centroid lined up with the monitor central point, shrinking in size from 150 mm down to 10 mm in regular 5mm steps between subsequent images. All squares were colored in black, i.e. the value of minimum luminance provided by the monitor, whereas the encircling frames were filled in with uniform white, i.e. the value of maximum luminance, and with a mid-valued gray for the second image set (**figure 4**). Frame color was then the only distinguishing feature between the image sets.

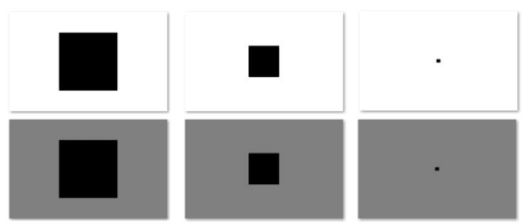

Figure 4. Samples displayed on screen from both image sets. From left to right, squares are shown of size 150 mm, 80 mm and 10 mm. Only a few pixels in the neighborhood of the centroid where visible through the mask slit.

Luminance values were measured prior to the experiment itself for full-screen white, medium grey and black, respectively resulting in $2.37{\times}10^2$ cd/m^2, $7.00{\times}10^1$ cd/m^2 and $0.18{\times}10^0$ cd/m^2. Contrary to expectations, luminance measurements of the focused spot showed no significant variations throughout the entire shrinking sequence of the minimum luminance square. By decreasing its size, the black to white boundaries were brought increasingly closer to the measured spot, in order to test whether light scattering could affect the central black patch luminance. No such effect was observed, with a total 0.01 cd/m^2 increment for the black and white image set that could hardly be distinguished from instrumental base fluctuations.

However, upon removal of the cardboard mask—the 10mm square still being displayed onscreen—the instrument suddenly shot upwards to 1.39 cd/m^2. All maximum luminance pixels, unfiltered and suddenly entering the viewing field of the device, were then deemed responsible for the veiling glare through instrument lenses. This, in turn, suggested that results obtained from preliminary measurements were also due to measuring device lens glare, and not to monitor intra-layer glare.

Measuring Color Checkers

Yet another experimental setup was arranged in order to further investigate this phenomenon. In a dimly lit room, one printed reproduction of a Macbeth ColorChecker was hung on the back wall (from now on left-background checker), and a second one on a black vertical panel standing a short distance from the wall itself (from now on right-foreground checker).

A variable intensity lamp was put in the middle, far from the wall, and in front of it a Konica Minolta Color Analyzer CA-2000. This instrument is a 2D color analyzer, measuring chromaticity and luminance distributions in two dimensions.

A scheme of the test setup seen from above is visible in **figure 5c**. Both color checkers faced towards the measuring device, though one was rotated 180° with respect to the other in such a way that both black patches lay closer to the lamp. The light from the lamp hit the color analyzer (**figure 5a**), and did not fall over any of the two checkers, with the possible exception of negligible contributions reflecting off the floor.

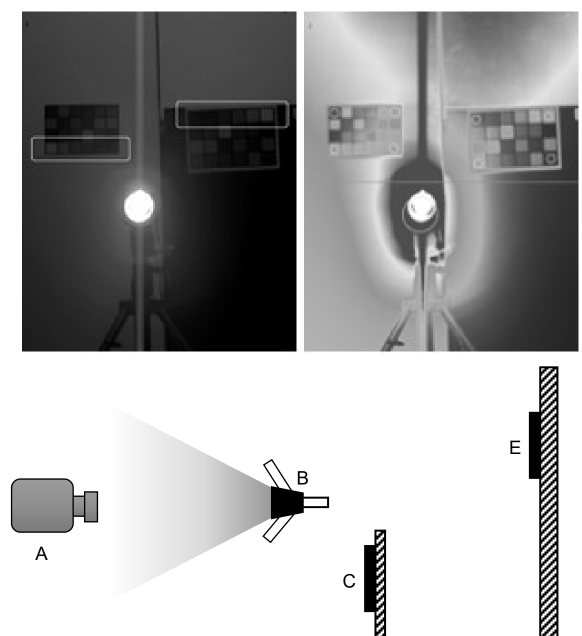

***Figure 5a**, **5b** and **5c**. Snapshot of the second experimental setup under a 400 mA lamp driving current. Both grey series (white boxes in 5a) always have* Black 2.0 *facing towards the lamp. A pseudo color luminance image of the same series is given in 5b, where glare is clearly perceivable as an intense halo surrounding the lamp and heavily bleeding over both color checkers. 5c shows a representation of the setup as seen from above, where: (A) CA-2000; (B) lamp on tripod; (C) right-foreground checker; (D) Black supporting panel; (E) left-background checker; (F) room wall.*

Snapshots were taken of the scene through the CA-2000 camera, under a constant ambient lighting and increasing levels of light coming from the lamp, sequentially with driving currents of magnitude 100 mA, 200 mA, 250 mA, 300 mA, 350 mA and 400 mA. Using the custom CA-S20w software, we sampled luminance values with measuring spots manually designed to cover the center of the patch while keeping a safe distance from the edges. Every spot was manually placed and double-checked.

All luminance measurements are given in Table 1 and Table 2 in cd/m^2, where every entry represents a checker patch named according to the official notation: **01**-*Dark skin*; **02**-*Light Skin*; **03**-*Blue sky*; **04**-*Foliage*; **05**-*Blue Flower*; **06**-*Bluish green*; **07**-*Orange*; **08**-*Purplish Blue*; **09**-*Moderate red*; **10**-*Purple*; **11**-*Yellow green*; **12**-*Orange yellow*; **13**-*Blue*; **14**-*Green*; **15**-*Red*; **16**-*Yellow*; **17**-*Magenta*; **18**-*Cyan*; **19**-*White 9.5*; **20**-*Neutral 8.0*; **21**-*Neutral 6.5*; **22**-*Neutral 5.0*; **23**-*Neutral 3.5*; **24**-*Black 2.0*. Chromaticity measurements are not provided, as they are beyond scope of this paper.

Table 1. Luminance [cd/m^2] of all left-background patches

Patch	100mA	200mA	250mA	300mA	350mA	400mA
01	8.14	9.96	10.82	11.29	11.31	11.82
02	20.36	22.70	23.90	24.72	24.85	25.70
03	11.10	14.23	15.74	16.73	17.05	18.37
04	11.64	15.71	17.60	19.07	20.23	21.72
05	16.08	21.23	23.73	25.67	26.87	29.08
06	23.93	29.63	32.37	34.55	35.90	38.29
07	19.79	21.79	22.75	23.42	23.54	24.35
08	7.42	10.08	11.35	12.14	12.32	13.42
09	16.56	20.48	22.23	23.59	24.13	25.65
10	9.86	14.83	17.20	19.00	19.93	21.99
11	28.45	34.35	37.25	39.45	40.91	43.28
12	32.30	38.80	41.91	44.47	46.07	48.84
13	5.26	7.39	8.47	9.01	9.13	9.86
14	11.78	14.81	16.36	17.34	17.61	18.94
15	12.82	17.04	19.01	20.50	21.17	23.00
16	35.84	41.41	44.05	46.19	47.60	49.94
17	18.70	25.30	28.45	31.02	32.51	35.37
18	14.52	21.80	25.38	28.17	30.09	33.23
19	38.43	41.07	42.29	43.17	43.37	44.46
20	26.19	29.61	31.16	32.34	32.62	34.04
21	18.80	23.41	25.55	27.22	28.02	29.90
22	14.33	20.23	23.05	25.26	26.68	29.19
23	11.97	19.53	23.10	26.08	28.15	31.50
24	12.09	21.24	25.50	29.32	31.90	35.76

Table 2. Luminance [cd/m^2] of all right-foreground patches

Patch	100mA	200mA	250mA	300mA	350mA	400mA
01	5.73	7.01	7.63	8.03	8.10	8.62
02	15.32	16.98	17.78	18.32	18.52	19.24
03	7.71	9.72	10.67	11.31	11.46	12.25
04	8.25	11.02	12.34	13.35	13.77	15.02
05	11.73	15.63	17.56	18.93	19.69	21.39
06	19.39	25.00	27.62	29.75	31.40	33.78
07	16.30	17.70	18.35	18.85	19.01	19.56
08	5.38	7.02	7.82	8.33	8.46	9.09
09	13.28	15.44	16.45	17.12	17.38	18.21
10	6.27	8.88	10.14	10.97	11.25	12.29
11	23.18	27.04	28.86	30.31	31.24	32.84
12	27.68	32.91	35.37	37.56	39.15	41.35

13	3.94	5.21	5.82	6.19	6.27	6.71
14	9.65	11.31	12.14	12.65	12.74	13.44
15	9.88	11.94	12.91	13.55	13.70	14.52
16	31.78	34.43	35.70	36.55	36.90	37.97
17	14.51	17.78	19.47	20.68	21.23	22.66
18	11.18	15.90	18.13	20.01	21.23	23.12
19	42.29	43.78	44.55	45.06	45.29	45.92
20	27.04	28.80	29.49	30.10	30.21	30.91
21	16.77	18.72	19.70	20.33	20.52	21.29
22	10.89	13.11	14.21	14.95	15.19	16.07
23	7.48	10.30	11.62	12.50	12.73	13.79
24	6.47	10.19	11.90	13.23	14.08	15.37

We computed a reference theoretical luminance value, one for each checker, starting from an estimate of the illuminant intensity taken from the white patch of each checker at 100mA, where the glare is supposed to be the lowest of the series. We are aware that, as reported more extensively in [2], estimated luminance from images always contains glare distortions. For this reason, estimated baseline has to be considered for presentational purposes only. The presence of glare in the instruments will be clear analyzing the data in their variation, not in their absolute values.

Accurate measures from [7] reports the following grey series (**figure 6**) for a CIE D50: *White 9.5*: **90.94**; *Neutral 8.0*: **58.50**; *Neutral 6.5*: **35.71**; *Neutral 5.0*: **19.12**; *Neutral 3.5*: **8.87**; and finally, *Black 2.0*: **3.17**. The reference luminance value was computed using the above-mentioned ratios and *White 9.5* in the 100 mA case, under the assumption that this particular patch was on both checkers far enough from the lamp on the image plane, and having the minimal glare. Reference illuminant luminance values were then computed for the left-background checker (3) and the right-foreground checker (4) as:

$$38.43cd/m^2 \times 100 \div 90.94 = 42.26cd/m^2 \quad (3)$$

$$42.29cd/m^2 \times 100 \div 90.94 = 46.50cd/m^2 \quad (4)$$

These values yield in turn both reference grey series, expressed in cd/m^2 in Table 3:

Table 3. Luminance [cd/m^2] of computed reference grey patches

	Left-background	Right-foreground
White 9.5	38.43	42.29
Neutral 8.0	24.72	27.20
Neutral 6.5	15.09	16.61
Neutral 5.0	8.08	8.89
Neutral 3.5	3.75	4.12
Black 2.0	1.34	1.47

Plots of luminance trends are shown for both grey series in **figure 7** and **figure 8**. Luminance increments from the reference values are readily apparent. For instance, the overall increment in cd/m^2 under a 400 mA current for both checkers (Table 4) are:

Table 4. Luminance increments [cd/m^2] of grey patches with respect to the computed reference (400 mA current)

	Left-background	Right-foreground
White 9.5	+6.03	+3.63
Neutral 8.0	+9.32	+3.71
Neutral 6.5	+14.81	+4.68
Neutral 5.0	+21.11	+7.18
Neutral 3.5	+27.75	+9.67
Black 2.0	+34.42	+13.89

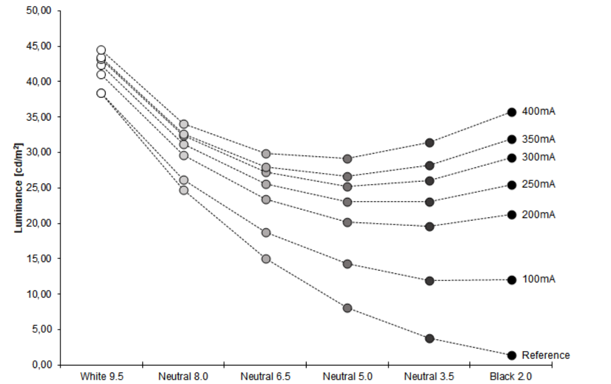

***Figure 7**. Luminance of the grey series patches of the left-background color checker. Each dotted line represents the series under different driving currents. Base luminance values (computed) are labelled as* **Reference**.

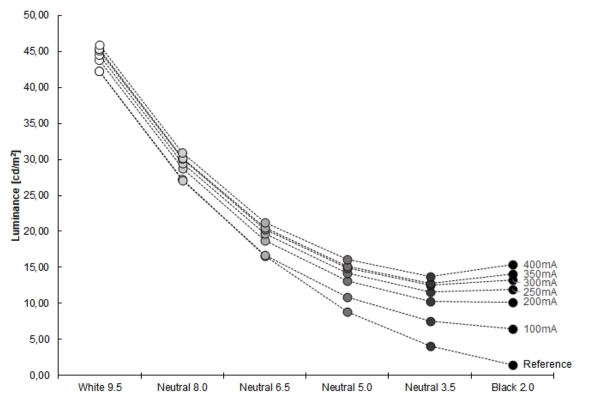

***Figure 8**. Luminance of the grey series patches of the right-foreground color checker. Each dotted line represents the series under different driving currents. Base luminance values (computed) are labelled as* **Reference.**

Values are also given (Table 5 and 6) of dynamic ranges of the left-background and of the right-foreground checker grey series, respectively, computed according to the standard definition, i.e. the ratio of the maximum to the minimum luminance. These are not always *White 9.5* and *Black 2.0*, as would be reasonably assumed. Names are provided in accordance, next to luminance values from the instrument in cd/m^2.

Table 5. Dynamic ranges of the left-background grey series

	Maximum		Minimum		
	Value	Patch	Value	Patch	Ratio
100 mA	38.43	White 9.5	11.97	Neutral 3.5	3.21:1
200 mA	41.07	White 9.5	19.53	Neutral 3.5	2.10:1
250 mA	42.29	White 9.5	23.05	Neutral 5.0	1.83:1
300 mA	43.17	White 9.5	25.26	Neutral 5.0	1.71:1
350 mA	43.37	White 9.5	26.68	Neutral 5.0	1.63:1
400 mA	44.46	White 9.5	29.19	Neutral 5.0	1.52:1

Table 6. Dynamic ranges of the right-foreground grey series

	Maximum		Minimum		
	Value	Patch	Value	Patch	Ratio
100 mA	42.29	White 9.5	6.47	Black 2.0	6.54:1
200 mA	43.78	White 9.5	10.19	Black 2.0	4.30:1
250 mA	44.55	White 9.5	11.62	Neutral 3.5	3.84:1
300 mA	45.06	White 9.5	12.50	Neutral 3.5	3.61:1
350 mA	45.29	White 9.5	12.73	Neutral 3.5	3.56:1
400 mA	45.92	White 9.5	13.79	Neutral 3.5	3.33:1

Discussion

Our initial attempt to measure intra-layer glare in monitors turned into an assessment of glare in the luminance measuring instruments, of which we have used and tested two very different types: for single spot and for 2D image (about 1 million points) measures. Both instruments have a lens to focus on the plane to be measured, and thus both turned out to be affected by glare.

The two checkers test is the more interesting. In the absence of glare, the central lamp, since not shining on the checkers, should have had no impact on patch luminance values. Results show otherwise: measured luminance variations are due to glare within the instrument optical system. A luminance increase was systematically measured for all patches on both checkers. The greater the lamp driving current, the greater the overall magnitude of the effect. Glare did not, however, equally affect all patches. As expected, proximity in the image plane to the higher luminance coming from the lamp accounted for greater luminance increments in the instrument. The closer the target to the source of glare, the steeper its luminance gradient. In other words, the spatial effects of glare are non-linear. Glare is then confirmed to be scene-dependent and spatially varying within an image, as shown in **figures 7** and **8**. A glance at both plots shows the grey series luminance profile of the left-background checker—furthest in space yet nearest on the image plane to the lamp—having a greater variation than that of the right-foreground checker.

Also because of glare, black patches within each series—again those nearest to the lamp—show a greater variation with respect to white patches. As a consequence, acquired dynamic ranges are compressed. Starting from the 100 mA series for the left-background checker, and the 250 mA series onwards for the right-foreground checker, dynamic ranges should on principle be computed as ratios of white to intermediate neutral greys, since black is no longer the minimum luminance patch. Because of the spatially varying nature of glare, some counterintuitive values can be observed. For instance, in the left-background checker 400 mA series, the maximum luminance patch is *Yellow*, not *White*, whereas the minimum luminance patch is *Blue*, not *Black 2.0*. These luminance values yield a dynamic range of about 5:1, while the standard dynamic range of a Macbeth color checker is about 29:1 under any uniform illuminant.

We have used printed reproductions of the color checker instead of real ones. Consequently, patch reflectances were not strictly identical to the ones of the original matte coatings. However, this has shown to be marginal for the outcome of the experiments. A distinct behavior emerges: luminance measurements are influenced by undesired glare in the instrument, whose spatial effects extend well beyond the immediate surroundings of its source, generating quite unpredictable effects in the overall scene.

Conclusions

The experimental data presented in this paper show that the intra-layer glare of a display might be negligible, especially when compared to the amount of glare of the lens in measuring device. Monitor performances deserve further testing, since the presented results are far from being conclusive.

At the same time, the experiments here reported highlight the problem of glare in the measuring instruments. This form of glare is usually more neglected, and yet it has been shown, even in high-end devices, to be both pervasive and non-linear, in a manner that is spatially varying and depends on the arrangement of light and dark areas in the scene.

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Authors Biographies

Simone Liberini received his Bachelor and Master of Science degrees in Biomedical Engineering at Politecnico di Milano. He briefly worked as a research fellow at Istituto di Bioimmagini e Fisiologia Molecolare, Milano, where he contributed to developing a quantitative image-based frame of assessment of parotid glands shrinkage in head-and-neck cancer patients. He is currently fellow frequenter at Università degli Studi di Milano, and is investigating the effects of glare on luminance and chromaticity measurements.

Matteo Paolo Lanaro started his PhD student in Computer Science at the University of Milan after graduating in Computer Science for Communications in 2016. He is a member of the MIPS Lab led by professor Alessandro Rizzi. His research is focused on investigating the sampling of photoreceptors in the human retina, and how their spatial distribution relates to the perception of color. His research fields also include glare, color vision deficiency and spatial color algorithms.

Maurizio Rossi, MSc, PhD. Associate professor of Lighting Design at Politecnico di Milano where he is the scientific manager of the Lab. Luce, and the director of the master in Color Design and Technology and the Master in Lighting Design & Technology. From 2012 to 2018 he was the President of the Associazione Italiana Colore. He is the editor-in-chief of the Color Culture and Science Journal. Since 2018 is member of the Executive Committee of AIC (International Color Association).

Alessandro Rizzi is full professor, Department of Computer Science, University of Milano. He has been one of the founders of the Italian Color Group, secretary of CIE Division 8, an IS&T Fellow and a past Vice-President. He is topical editor for Applied Color Science of Journal of Optical Society of America A and associate editor of Journal of Electronic Imaging. In 2015, he received the Davies medal from the Royal Photographic Society.