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Acceptance levels for image quality factors

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Abstract

In order to determine the lowest light level at which a digital camera can still deliver acceptable images, acceptance thresholds must be established for all related image quality factors. ISO 19093 [1] describes these factors and how they can be measured. However, the acceptance thresholds may depend on the application for which the images were captured, as well as on people's individual tolerance for degradation in the different image quality factors. To generate a standard set of tolerance levels for photographic applications, a psychophysical experiment was performed, as described in this paper.

First, a group of 23 image quality experts participated, followed by 16 people with no specific experience in imaging.

The same experiment was repeated for the specific application of security cameras. The set of images, as well as the questions asked of the participants, were adapted to the use case. For the security application, 27 participants with a background in security camera imaging took part.

The image quality factors

What happens in a camera when the light level decreases? Firstly, the camera tries to compensate for lower light levels by opening the aperture, increasing the exposure time, and finally increasing the sensitivity — or, more precisely, the signal amplification. Opening the aperture (f-stop) reduces the depth of focus, which is often acceptable, particularly for cameras with small sensors and their related large depth of field, until the maximum aperture is reached. Increasing the exposure time is acceptable until, in the case of a handheld camera, the image quality starts to degrade due to human hand shake. If the camera does not have an image stabilization mechanism, there is a rule of thumb for the longest acceptable exposure time. With image stabilization mechanisms, this exposure time can usually be increased. The determination of this limitation depends on the acceptable amount of blur. If this amount is known, the measurement is easy using a slanted edge. Once the maximum aperture and longest exposure time have been reached, the camera starts to increase the amplification level, as indicated by the sensitivity settings. Increased signal amplification makes noise, which is always present in the system, more visible. Modern cameras attempt to reduce noise in the final images, which usually results in a loss of low-contrast fine detail, also known as texture, because the algorithms are limited in their ability to differentiate between noise and texture in real images. Depending on the algorithm used to reduce noise, it is also possible that the chroma or saturation of colors will be reduced.

The procedure described in ISO 19093 [1] defines the image quality factors that need to be determined to establish how the system balances quality at different light levels, and at which light level compensations reach their limits.

The factors that need to be determined are

Resolution: the amount of blur introduced by handheld movement increases with exposure time and is measured as limiting resolution, also known as SFR 10 (as described in ISO 12233 [2]). Note that the sSFR method needs to be used, as a potential sharpening process may preserve edges to a certain extent.

Noise: when the sensor signal is amplified, the noise is also amplified and becomes visible. ISO 15739 [3] describes how to measure noise, and the visual noise measurement described in the standard converts the visibility of noise in images into a quantitative value.

Exposure: when the scene is darker, e.g. after sunset, images exposed in the same way as daylight images often appear too bright. For this reason, night scenes are intentionally exposed lower than usual daylight images. To keep noise down while still using acceptable exposure times, some cameras intentionally underexpose images. However, at a certain point, images become too dark and are no longer considered acceptable. The reproduction level of a mid-grey patch in the scene indicates how much the image has been underexposed.

Texture: modern cameras use noise suppression when the noise level becomes excessive, and the algorithms used for this purpose are continually improving. AI enables the processor to differentiate between noise and scene elements. However, certain scene structures are still affected by noise suppression; these are mostly lower-contrast, fine-detail elements. ISO 19567-2 [4] describes how to determine texture loss in images.

Last but not least, noise suppression can also impact the chroma in images, meaning that denoising in the color channels only can result in desaturated colors. This can easily be determined by examining the chroma values of colors in a test chart.

The procedure used

To determine the acceptance thresholds, series of images were generated that showed a degradation in each of the image quality factors. Degradation was limited to one factor at a time so as not to confuse observers regarding which aspect to focus on. As it is difficult for ordinary people to judge quality using a test chart, and their judgement may vary depending on the captured scene, a series of three natural images representing typical scenes was selected, as well as a test chart to obtain the required measurement results for each factor.

The original images were then degraded step by step in Adobe Photoshop using the appropriate filters/algorithms. For each factor, a series of images was generated, starting with the original image and progressing through 10 steps of degradation. The series of images of the test chart were then analyzed using Image Engineering's IQ-Analyzer software, which is based on ISO standards.

Image selection for photographic images

The images used in the experiment should depict typical scenes relevant to the specific application. For photographic images, scenes that consumers typically capture with their cameras should be used. Three typical scenes for conventional photography come to mind and are extracted from the statistical analysis mentioned in references [5] and [6]. These are: an image showing people; an image showing a landscape; and an image showing food.

Figure 1: The selected food image.

Figure 2: The selected landscape image.

Figure 3: The people image.

Image selection for security camera application

Security cameras are typically used to monitor streets, driveways and courtyards, where people and cars are present under a variety of lighting conditions.

Figure 4: A typical daylight scene for a security camera.

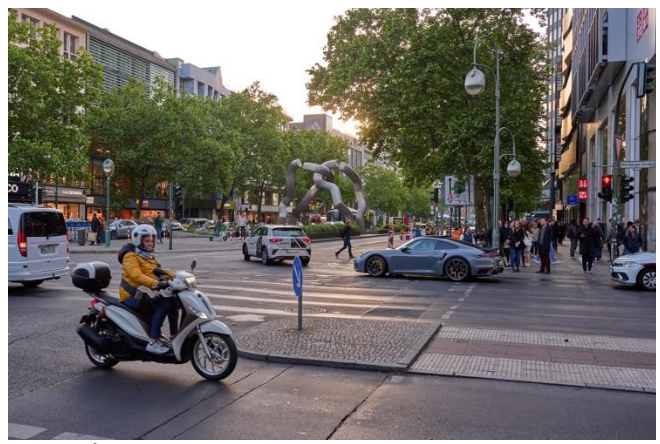

Figure 5: Street around sunset.

Figure 6: People at a bus stop at night.

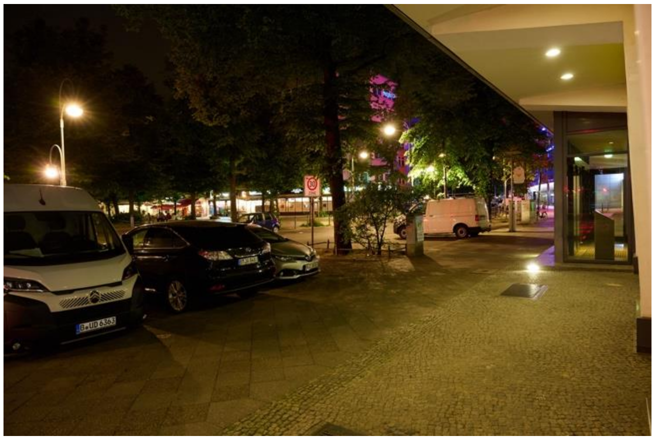
Figure 7: Parked cars at night.

Image quality degradation

The images were degraded using the tools available in Adobe Photoshop. Each time, the original image was opened, and the selected degradation algorithm was applied.

The following Photoshop tools were used:

1. Chroma decrease: Image_corrections_Hue/Saturation (-0% to -100% in 10% steps)
2. Exposure decrease: Image_corrections_Exposure (0 to -5.0 in steps of 0.5)
3. Noise increase: Filte_Noise_add Noise (0 to 20% in steps of 2%)
4. Resolution decrease: Filter_Blur_gaussian blur (0 to 5 in steps of 0.5)
5. Texture decrease: Filter_Noise_Median (0 to 10 in steps of 1)


Figure 8: A chroma decrease series.


Figure 9: An exposure decrease series.

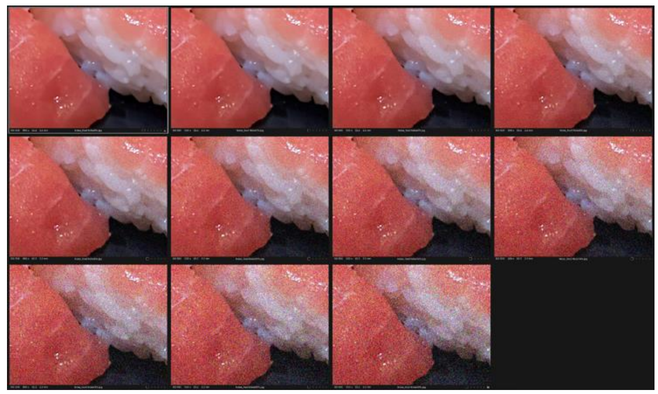
Figure 10: A noise increase series (cropped showing part of the images).

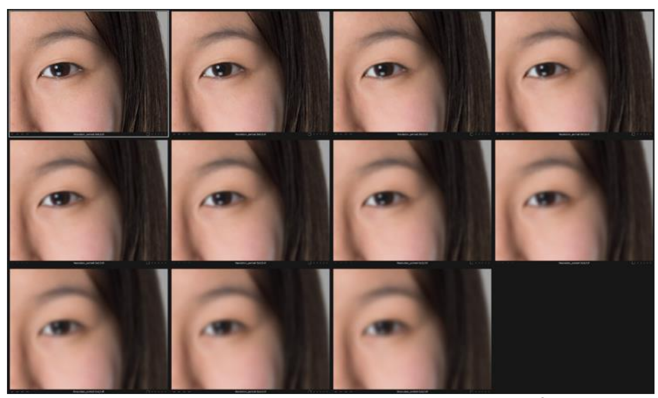
Figure 11: A resolution decrease series (cropped showing part of the images).

Figure 12: A Texture degradation series (cropped showing part of the images).

Relation to quantitative measurement results

To put the degradation of the real images into context with regard to measured image quality values, the same degradations were applied to a test chart that could be analyzed using Image Engineering's iQ-Analyzer X software.

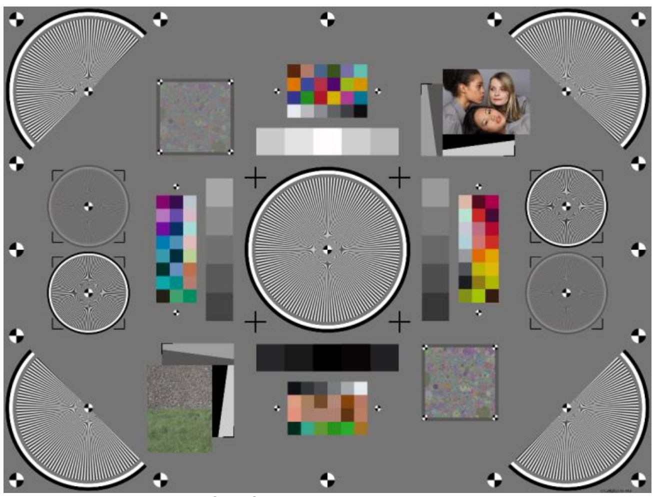

Figure 13: The synthetic file of the test chart that was used to determine the measurement values.

The following measurements were achieved:

Table 1: The average chroma of the 18 top color patches in the chart was determined for Chroma (C*).

Chroma_Ch-0	C* 52
Chroma_Ch-10	C* 48
Chroma_Ch-20	C* 43
Chroma_Ch-30	C* 39
Chroma_Ch-40	C* 34
Chroma_Ch-50	C* 29
Chroma_Ch-60	C* 23
Chroma_Ch-70	C* 18
Chroma_Ch-80	C* 12
Chroma_Ch-90	C* 6
Chroma_Ch-100	C* 0

Table 2: For Exposure the L* value was determined for the background which was set to L* 50 in the original image:

Exposure_ Ex-0,0	L*50
Exposure_ Ex-0,5	L*43
Exposure_ Ex-1,0	L*37
Exposure_ Ex-1,5	L*31
Exposure_ Ex-2,0	L*27
Exposure_ Ex-2,5	L*23
Exposure_ Ex-3.0	L*19
Exposure_ Ex-3.5	L*16
Exposure_ Ex-4.0	L*13
Exposure_ Ex-4.5	L*11
Exposure_ Ex-5.0	L*08

Table 3: For Noise the visual Noise values were determined according to ISO 15739:2017 resulting in:

Noise_0%.tif	0.164
Noise_2%.tif	2.211
Noise_4%.tif	4.309
Noise_6%.tif	6.983
Noise_8%.tif	8.709
Noise_10%.tif	11.580
Noise_12%.tif	13.456
Noise_14%.tif	15.711
Noise_16%.tif	18.077
Noise_18%.tif	19.881
Noise_20%.tif	21.867

Table 4: For Resolution the limiting resolution (SFR 10) on the central high contrast siemens star was determined according to ISO 12233 sSFR measurement (values are in LP/PH).

Resolution_So0,0.tif	Center	NA
Resolution_So0,5.tif	Center	1016.191
Resolution_So1,0.tif	Center	774.152
Resolution_So1,5.tif	Center	533.504
Resolution_So2,0.tif	Center	365.350
Resolution_So2,5.tif	Center	282.738
Resolution_So3,0.tif	Center	250.524
Resolution_So3,5.tif	Center	209.820
Resolution_So4,0.tif	Center	188.167
Resolution_So4,5.tif	Center	168.601
Resolution_So5,0.tif	Center	NA

Table 5: For Texture the values were determined according to ISO TS 19567-2 (values are in LP/PH).

Texture_ Te0.tif	DeadLeavesBR-Full-Cross	1079.500
Texture_ Te1.tif	DeadLeavesBR-Full-Cross	754.635
Texture_ Te2.tif	DeadLeavesBR-Full-Cross	456.046
Texture_ Te3.tif	DeadLeavesBR-Full-Cross	323.184
Texture_ Te4.tif	DeadLeavesBR-Full-Cross	250.825
Texture_ Te5.tif	DeadLeavesBR-Full-Cross	193.682
Texture_ Te6.tif	DeadLeavesBR-Full-Cross	169.047
Texture_ Te7.tif	DeadLeavesBR-Full-Cross	147.676
Texture_ Te8.tif	DeadLeavesBR-Full-Cross	85.246
Texture_ Te9.tif	DeadLeavesBR-Full-Cross	53.758
Texture_ Te10.tif	DeadLeavesBR-Full-Cross	58.263

The experimental setup

In a relatively dark environment with an illumination of close to 80 lux on the table, a MacBook Pro was used in combination with an LG 4K monitor that was calibrated using a Calibrite Display Pro HL. The viewing distance for each pixel was calculated to be 60 cm. PhaseOne CaptureOne was used in full-screen mode to display the image file name and determine the threshold image for each series. The images were displayed, starting with the original and continuing with increasing degradation of the same image. After the maximum amount of degradation had been reached, the display switched to the next image. The image quality aspects were displayed in the following order: Chroma, Exposure, Noise, Resolution, and Texture.

For the photographic application, the participants were asked to select the image with the lowest quality that they would still find acceptable if the image would be important to them and they wanted to hang it on a wall in their living room. In each series of 11 quality levels, they had to select the relevant image.

For the security camera application, participants were asked to select the image with sufficient quality to allow them to see everything important for evaluation, such as face recognition, license plate identification and colors of clothing.

The final results

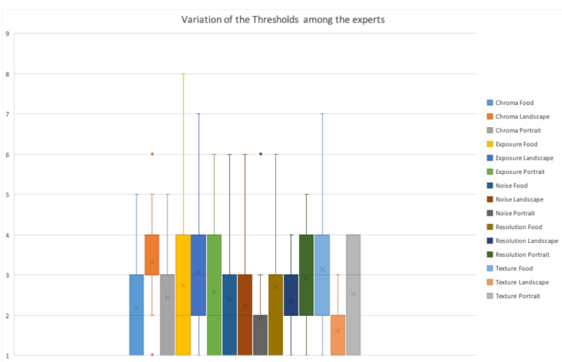

Figure 14: The individual Image selection among the experts.

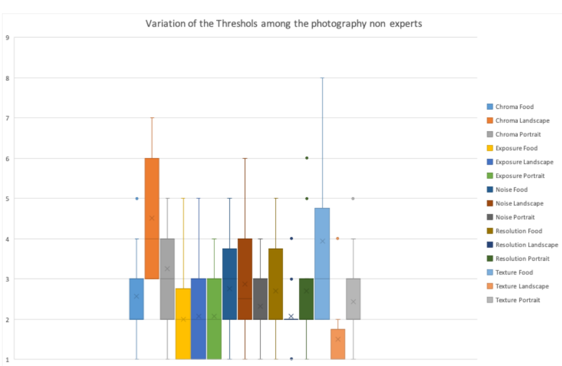

Figure 15: The individual Image selection among the non-experts.

Interestingly there is a slightly broader variation in the results among the experts compared to the non-experts. And especially the landscape image shows a relatively small variation especially for texture and resolution.

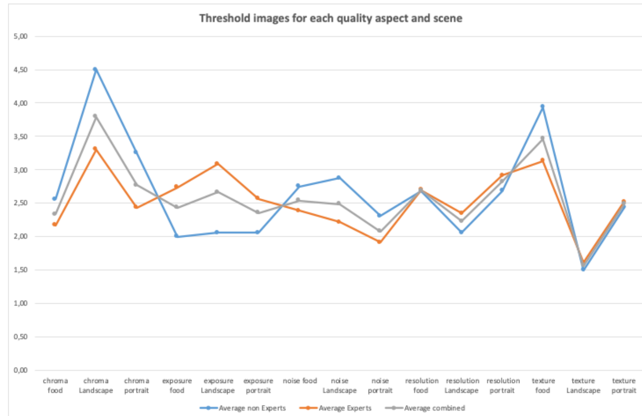

Figure 16: Selected last acceptable image for photographic applications sorted by expert and non-expert evaluation.

In some image quality aspects like chroma, exposure and noise there is a significant difference between experts and non-experts.The non-experts tolerate a higher amount of Chroma loss and noise, however with exposure they are less tolerant than the experts.

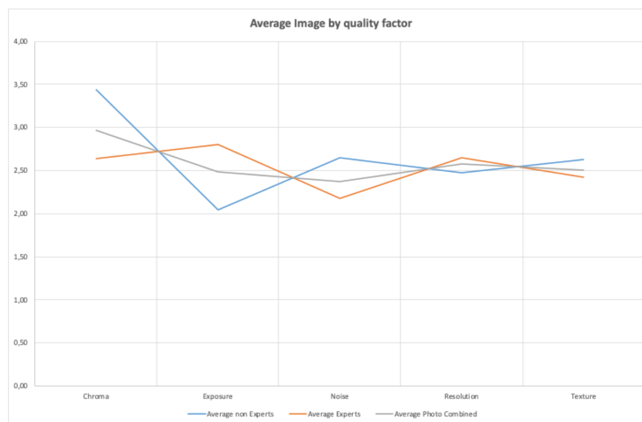

Figure 17: The judgement by Expert and non-Experts for each image quality factor (averaged over the 3 scenes).

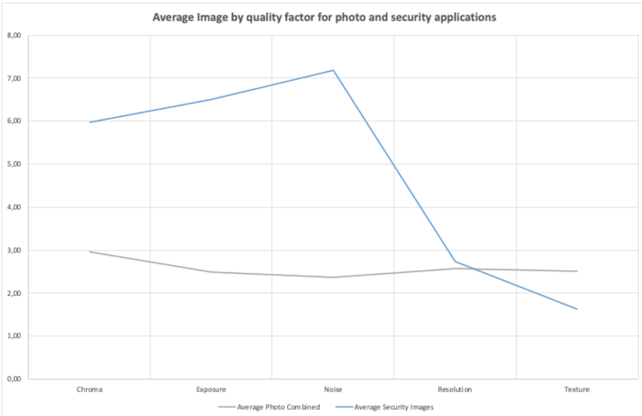

Figure 18: The judgement of the last acceptable image per quality factor from the photographic point of view and the security application point of view.

For security cameras the participants accepted a higher loss in chroma and exposure and they also tolerated higher noise level. The difference can be found in the application in combination with the question asked to the participants. Even for the higher degradation levels the participants thought that they would still be able to differentiate colors or identify people.

The average values for the selected images were converted into threshold values for the image quality factors using the aforementioned image quality measurement results.

Table 6: Transferring image judgements into quality thresholds for photography

Image Selections tranferred to measurement results	Chroma	Exposure	Noise	Resolution	Texture
Average non Experts	35,72	37,32	5,98	669,33	434,06
Average Experts	39,88	34,24	4,94	652,29	447,22
Average combined	38,17	35,51	5,37	659,28	441,82
Proposed Thresholds (rounded) for implementation into ISO 19093	Cmin = 38 Cmin / Cref = 0.75	min L* mid grey = 35	Max visual Noise 5,3	Min limiting Resolution 650 LP/PH	Min SFR10 for Texture 450 LP/PH

Table 7: Transferring image judgements into quality thresholds for security applications

Threshold image by aspect	Chroma	Exposure	Noise	Resolution	Texture
Average Image	5,98	6,51	7,19	2,74	1,63
Related measurement	22,48	19,13	16,00	643,56	498,05
Proposed Threshold (rounded) for implementation into IEC 62676-5	Cmin = 22 Cmin / Cref = 0.45	min L* mid grey = 19	Max visual Noise 16	Min limiting Resolution 650 LP/PH	Min SFR10 for Texture 450 LP/PH

Conclusions

When we look at image thresholds, it is not surprising that judgements of photographic images vary considerably depending on the scene. This is particularly evident in texture, especially in portraits and landscapes, and also in chroma, depending on its importance to the individual scene. The results show some variation between experts and non-experts in certain areas, whereas in others, such as resolution and texture, both groups are similar.

For security applications, the tolerance levels for chroma, exposure, and noise are significantly higher because the requirement is not for an aesthetically pleasing image, but for an image that allows faces, clothing colors, and license plates to be identified. Although there are slight variations in resolution and texture between the two applications, it makes sense to harmonize the proposed thresholds for these factors.

Overall, the results for both application fields suggest a set of thresholds that can be implemented in the standards.

Implementation in ISO 19093 and IEC 62676-5

The thresholds derived from this experiment will be proposed to the two standards groups alongside this paper. Whether the proposed values will be accepted as described is subject to the votes of the nations involved in developing the standards.

References

[1] ISO 19093 Digital Imaging – Low light performance

[2] ISO 12233 Digital Imaging – Resolution and spatial frequency responses

[3] ISO 15739 Digital Imaging – Noise measurements

[4] ISO 19567-2 Digital Imaging – Texture measurement – Part 2: Texture analysis using stochastic pattern

[5] D. Wueller, R. Fageth, Statistic analysis of millions of digital photos, March 2008, Proceedings of SPIE - The International Society for Optical Engineering, DOI:10.1117/12.766702

[6] Dietmar Wueller, Reiner Fageth, " Statistic analysis of millions of digital photos 2017 " in Proc. IS&T Int'l. Symp. on Electronic Imaging: Photography, Mobile, and Immersive Imaging, 2018, pp 344-1 - 344-4

Author Biography

Dietmar Wueller studied photographic technology at Cologne University of Applied Sciences. He founded Image Engineering, an independent camera testing laboratory which has developed into one of the world's leading suppliers of testing equipment. He is the German chair of the DIN standardization committee for photographic equipment and is also active in ISO TC42, the IEEE and the EMVA (European Machine Vision Association), as well as other standardization activities.