The usage of digital cameras as luminance meters

Dietmar Wüller[a], Helke Gabele[b]
[a]Image Engineering, Augustinusstrasse 9d, 50226 Frechen, Germany;
[b]FRAMOS Electronic Vertriebs GmbH, Zugspitzstrasse 5 Haus C, 82049 Pullach, Germany

ABSTRACT

Many luminance measuring tasks require a luminance distribution of the total viewing field. The approach of image-resolving luminance measurement, which could benefit from the continual development of position-resolving radiation detectors, represents a simplification of such measuring tasks.
Luminance measure cameras already exist which are specially manufactured for measuring tasks with very high requirements. Due to high-precision solutions these cameras are very expensive and are not commercially viable for many image-resolving measuring tasks. Therefore, it is desirable to measure luminance with digital still cameras which are freely available at reasonable prices.
This paper presents a method for the usage of digital still cameras as luminance meters independent of the exposure settings. A calibration of the camera is performed with the help of an OECF (opto-electronic conversion function) measurement and the luminance is calculated with the camera's digital RGB output values. The test method and computation of the luminance value irrespective of exposure variations is described. The error sources which influence the result of the luminance measurement are also discussed.

Keywords: digital camera, luminance, OECF measurement, exposure value

1. INTRODUCTION

Many measuring points are necessary for the determination of luminance ratios in a whole scene. If a conventional luminance meter, which can only perform point-by-point measurements, is used for such large-scale assessments, the process of measuring would be very time-consuming. Likewise, measuring small details can not be realised with a luminance meter because of its fixed measuring angle, which is usually not small enough. Using the image-resolving measuring method provides advantages over the luminance measurement with a one-dimensional detector. For example, the position-resolving representation simplifies the luminance evaluation. All information about luminance in a scene can be recorded in one image. Therefore, the connection between different measuring points can be easily and quickly assessed, both visually and metrologically. Also, this method is less time intensive because a measurement on location can occur much more quickly than with a conventional luminance meter, since all measuring points can be recorded at once within only one image. Luminance constancy is an important point, too. Because all measuring points can be recorded at the same time, the existing luminance can not be varied during the measurement. Reproducibility is also an advantage compared to the point-by-point luminance measurement because the measured image can be saved and permits repetition of the evaluation at a later time.

The purpose of this work was to determine if it is possible to measure luminance with digital still cameras (DSC) which are freely available. For this, a calibration of the digital camera was necessary, which needed to be undertaken according to the standard for the determination of the OECF curve. The calibration assigned the digital output values to different input luminance, in regard to the individual characteristic response of a camera. In addition to calibration, the characteristic response of a digital camera needed to be examined to see if it remained unchanged for different exposure conditions. A calculation of the luminance based on the digital output values of a camera needed to be found, which could be applied to all digital cameras, independent of the exposure. Also, a quick and simple method needed to be prepared for calibration, as well as a subsequent test of certain camera-parameters, which could influence the suitability of the camera for the use of luminance measurements. Another requirement was that the inspection should be performed with cameras of all price classes.

Difficulties came about through the use of image-processing algorithms, which influence the camera's characteristic response. As a user one can only partially influence the image-processing, which is already performed inside the camera.

Digital Photography III, edited by Russel A. Martin, Jeffrey M. DiCarlo, Nitin Sampat, Proc. of
SPIE-IS&T Electronic Imaging, SPIE Vol. 6502, 65020U, © 2007 SPIE-IS&T · 0277-786X/07/$18

Aside from this, the manufacturers provide no information about their large-scaled development of these algorithms. In addition, a digital camera does not possess the precision which is expected from a measuring device. Therefore, one can assume that a typical digital camera will not yield such exact measurement results, as would be the case with a digital camera that has been specially manufactured for luminance measurement.

2. TEST METHOD

The following camera types were selected for the accomplishments of the main tests. As d-SLR cameras the Nikon D2X as a professional camera and the prosumer camera Canon EOS 350D were chosen. The compact cameras of two different price classes were the Nikon Coolpix 8400 and the Fuji Finepix F10.

There were two luminance meters in use as measurement devices. The MAVO-Monitor from Gossen was used for measuring the luminance of the different luminance fields of the calibration test chart. This device is only usable for back lighted or luminous surfaces. The second meter was a spot luminance meter with an SLR optical system from Minolta with a 1° acceptance angle and a TTL viewing system to allow an accurate indication of the area to be measured.

2.1. Camera settings

The utilized data format is JPEG, due to its very simple operation and the fact that all cameras are able to store such data. The compression should be minimized, thereby reducing the compression error. In order to get best results, the auto white balancing function should be set (see Section 4.1.5). Any image improvements (e.g. sharpening, special colour settings) should be disabled. As no additional light is permitted for measuring luminance, the flash should be turned off. All camera settings used during calibration should be reported. Consistent starting conditions will always be maintained; these settings should be adopted for measuring luminance.

2.2. Calibration

A digital camera has to be calibrated first before using it for measuring luminance. The calibration defines which digital output value relates to which luminance input signal. This relationship between scene luminance and digital output levels of an opto-electronic digital image capture system is called opto-electronic conversion function (OECF). The measurement method and data analysis is described by the International Standard ISO 14524[1]. Here the measurement for camera calibration is equivalent to this ISO standard. The only deviation from this standard is the captured test chart. It has 20 patches (instead of 12 as mentioned in the standard) and an object contrast of 10000:1, because most digital cameras today are in a position to reproduce such a high object contrast. A uniform illumination of this transmission target is achieved through the use of an ulbricht integration sphere equipped with daylight illumination (D55). When the test image is captured it is important to ensure that the grey fields are located in the middle of the camera's field of view; this is due to vignetting. After the proper exposure is determined, so as to ensure saturation in the lightest patch, ten exposures are taken successively. These images are evaluated with a Photoshop-Plugin to get a mean value of at least 64 x 64 pixels of the 20 patches, while the constancy of the exposure of these ten images is simultaneously calculated. The presentation of the results in the ISO standard is defined in order to plot the digital output level vs. the logarithm of input luminance. In this case of luminance measurement it is advantageous to plot the input luminance vs. the digital outputs, because a polynomial approximation is calculated due to this resulting curve (see Figure 1).

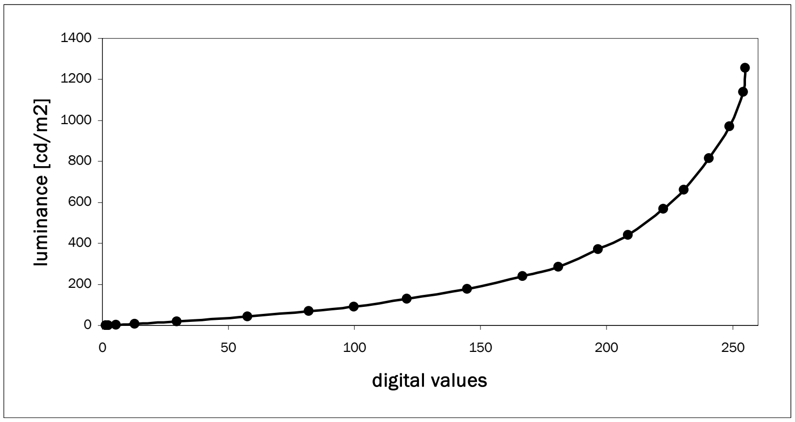

Fig.1. OECF curve plotted input luminance against digital values

2.3. Measurements

After calibrating the camera, some tests are carried out to see what happens with the shape of the characteristic line when different conditions, compared to those during calibration, dominate the exposure. Consequent tests were also done to see how cameras react to changes in exposure settings.

2.3.1. Constancy of exposure

The measurement of the constancy of exposure is determined by calculating the standard deviation of the digital output values from the 20 patches of the OECF test chart of all ten pictures which were taken during calibration. Therefore the amount of standard deviation, the repeatability of exposure with the same f-stop settings, exposure time and ISO speed can be assessed (see Section 4.1.3.).

2.3.2. Sensitivity

By changing the ISO speed it can be established if the channel amplification works accurately. Specifically, it was noted that if the camera indicated the correct aperture and exposure time, it will always obtain the same exposure value (see Section 4.1.2.).

2.3.3. Change in luminance

The luminance of the target was reduced to allow a closer look at the change in the OECF curve when the exposure value is different from its calibration. Reducing brightness was achieved by suspending a grey foil in front of the chart. As was to be expected, the shape of the new OECF curve (plotted log luminance against digital values as mentioned in ISO 14524, see Figure 2) is exactly the same as the calibration OECF, it just shifted to the left by a factor.

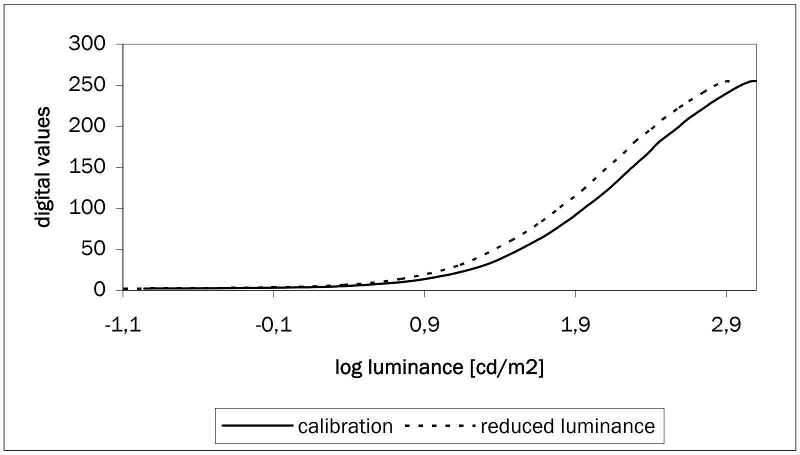

Fig 2. Calibration curve and the curve obtained by reducing luminance

2.3.4. Over and underexposure

Luminance measurement should work for under or overexposed images also. In use it can occur that the luminance of an object is not located in the range of evaluation by capturing the object with automatic exposure. Therefore, the picture has to be purposely taken with an under or overexposure. In these cases, a series of exposures of the OECF target were made. This was usually done by using the EV compensating feature; however, a manual exposure series was made in addition (if possible) to test if the results are more reliable. The OECF curves are also of the same shape as the calibration curve, but shifted to the left or right (see Figure 3).

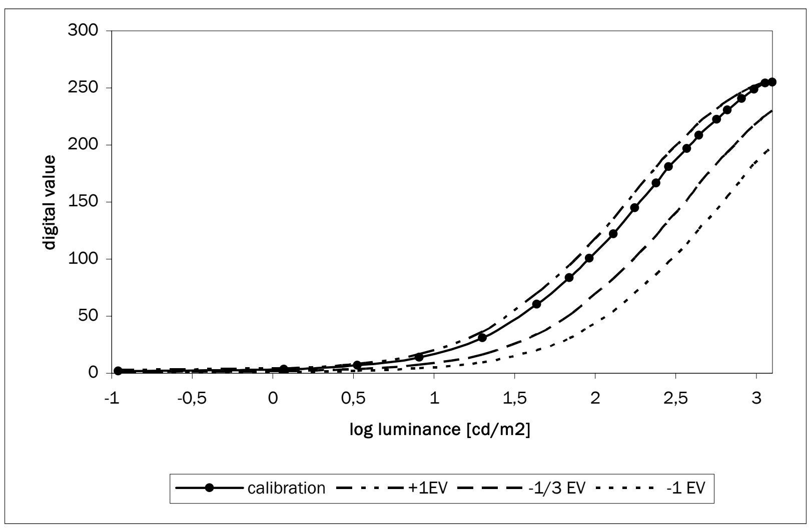

Fig. 3. Curves of over and under exposure of ± 1 EV with EV compensation of the camera

2.3.5. Different objects in a normal light scene

For the last test a scene with different objects was arranged and illuminated with a halogen light filtered to daylight. These objects were unicoloured and had less structure. The luminance of these was measured with the spot luminance meter and compared with the calculated luminance. Previous tests were all performed with the neutral grey test chart. Therefore it was interesting to see if the luminance measurement works in a normal light scene with a few coloured objects. As expected, the measurements of coloured objects showed a higher rate of deviation than those of neutral objects.

3. CALCULATION OF LUMINANCE

From the test explained in the previous section it can be determined that the characteristic line of cameras always has the same shape, no matter how the image is exposed or which scene luminance is present. It can be assumed that these curves are shifted from the calibration curve by a factor depending on the exposure variations. Thus, the obvious solution is to calculate the luminance by using the exposure value. The exposure value (EV) is defined in ISO 2721[2]. Each single value represented by the exposure value combines shutter time *t* and f-number *k* combinations which result in the same exposure (at unchanged lighting conditions and the same ISO speed setting).

$$2^{EV} = \frac{k^2}{t} \tag{1}$$

With the difference of the current exposure value to the exposure value of calibration, along with the digital output, the scene luminance can be determined.

3.1. Transformation of output RGB data into CIE Y value

The CIE XYZ y(λ) curve is nearly equivalent to the spectral luminous efficiency of the human eye for photopic vision. Hence, this value is able to make a direct statement about the luminance of colours. In the camera intern image processing the linear RGB data of the camera (device dependent data) are approximated to XYZ colour space by a linear transformation[3,4]. Further it is to be assumed that the output data of a digital camera is in the sRGB colour space[5]. Therefore, the CIE Y value can be found by employing the following defined equation on linear sRGB data[5].

$$Y = 0.2162\ R_{linear} + 0.7152\ G_{linear} + 0.0722\ B_{linear} \tag{2}$$

Thus, for calculating only the brightness of a scene with digital output data, linear RGB output values are needed for obtaining the CIE Y value.

The native linear response of an image sensor is not received when measuring the OECF of a digital camera based on a JPEG or Tiff image. The nonlinearity of the OECF curve corresponds to a gamma correction introduced in the image processing system of the camera. One consideration for procuring linear data was to calculate the CIE XYZ colour space from the nonlinear sRGB output data by using the transformation mentioned in IEC 61966-2-1[5]. By applying this calculation to the nonlinear output data the resulting curve should have a linear shape. However, the resulting curves of three of four cameras tested appeared similar to that in Figure 4.

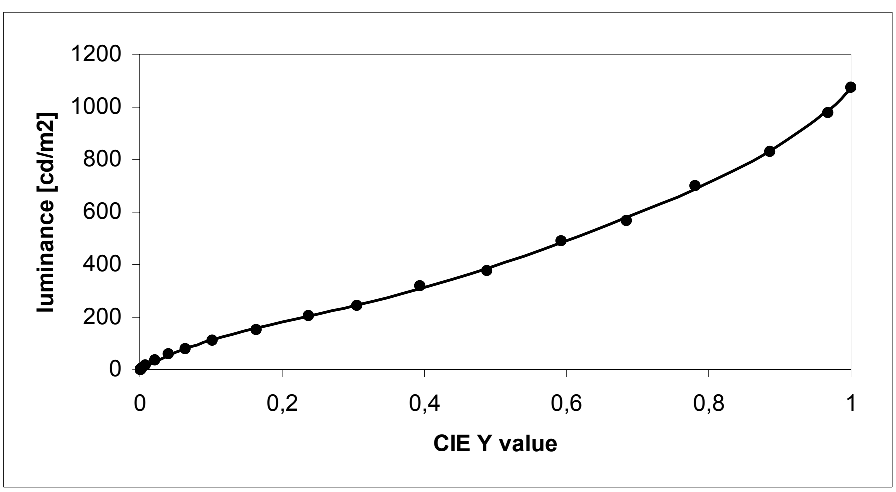

Fig. 4. Curve from Fuji F10 with CIE Y value calculated from sRGB data

Contrary to expectation, the curves are not continuously linear. Especially in the lower digital values, it is recognizable that the gamma value is lower than the sRGB gamma value of 2.4. Many manufacturers play to the customer's desire of getting pleasant pictures out of their camera. They go beyond a gamma correction and apply more of an S-shaped curve on the linear camera data to achieve a pleasing representation of the image on a monitor or print. That means, among other things, that there are still some details to distinguish in dark areas and in conditions of high luminance the manufacturers perform an effect called highlight compression.

Because of the nonlinearity of the resulting curve, this approach is not effective for producing linear data. Each manufacturer has its own method of changing the tonal response of camera data for obtaining pleasant pictures. For example, applying the calculation to the OECF curve of the Nikon D2X produces a nearly linear straight line. The professional dSLR camera does not manipulate the camera data to the extent that the consumer camera Fuji F10 does.

In order to derive a method for measuring luminance with nearly all types of digital cameras, it is necessary to have a method for attaining linear output data which can apply to all digital cameras. The first step is to approximate the curve obtained by the OECF measuring data by a sixth-degree polynomial. This is achieved by the method of the least square. Afterwards, a linearization of this approximated curve is achieved by creating a look-up table (LUT) with the help of the sixth-degree polynomial. This LUT maintains the nonlinear output data according to the desired linear values. Now, it is possible to calculate the approximated CIE Y value by applying these linear values in Equation 2.

3.2. Calculation with the exposure value (EV)

The calculation of luminance has to be irrespective of exposure variations. The calibration should be taken as a basis for all luminance computations. First, the current output data are assigned to luminance in the calibration curve. As concluded from the camera tests, the new exposure curves are apparently shifted from the calibration curve by a factor. To obtain the current luminance, the determined luminance of calibration is to be multiplied by a certain factor. This factor has to contain the difference of exposure between the calibration and the new exposure.

From the definition of illuminance of an image sensor and the definition of aperture and exposure value the following equation can be derived:

$$L_{new} = L_{cal} \cdot 2^{(EV_{new} - EV_{cal})} \cdot \frac{S_{ISO_{cal}}}{S_{ISO_{new}}} \tag{3}$$

Equation 3 represents the calculation of a current luminance dependent on the current exposure settings and the luminance and exposure settings of the calibration.

To estimate the luminance in a photo the user has to declare its exposure data, such as current aperture, exposure time and the ISO speed. In most cases information pertaining to exposure is stored in the Exif data. In addition, the RGB values of the area which wants to be evaluated have to be declared in order to calculate the luminance of calibration L_{cal} using the LUT and Equation 2.

3.3. Restriction of the digital output values

Due to measurement errors and the shape of the camera's characteristic curve an upper and lower limit for the digital values has to be determined which can be used for the calculation of the luminance value.

A test of four different luminance meters shows that there are high deviations in the measuring results[11] especially in the lower luminances. Also, the sixth-degree polynomial which describes the characteristic curve can oscillate in the range of the lower digital values. Dependent on the shape of the OECF curve, the polynomial oscillates sometimes strongly and sometimes only insignificantly.

The restriction of the higher digital values also depends on the shape of the characteristic curve. As one can see in Figure 1, the measuring points are irregularly distributed over the luminance range. The lower half of the luminance range is determined by 15 measuring points and the upper half by only five measuring points. These are too few data points for a reliable approximation. In the higher luminances the OECF curve is very steep in contrast to the flat part of the curve in the lower luminance range. In the steep part, the luminance area between two digital values is too large for a reliable evaluation of luminance. This can result in high absolute deviations of the current luminance. In order to evade this problem, the upper limit is determined by the gradation of the OECF curve. On the basis of test experiences, digital values from a gradient smaller than 15 should only be used for luminance evaluation. The maximum digital values are located between 225 and 245, dependent on the shape of the OECF curve.

4. SOURCES OF ERROR

4.1. Camera error

4.1.1. Settings of aperture and exposure time

The precision of the adjustment from aperture and shutter are associated with permissible tolerances, as mentioned in DIN 19016 and 4522-1[6,7]. The exposure time of the two dSLRs were measured and compared with the time set on the camera. By means of taking a picture of several LEDs which light up one after another with an adjustable frequency, the real shutter time can easily be determined. This test shows (the test data can be found in[11]) that a camera's set shutter time of for example 1/250 sec. in reality amounts to an exposure time of 1/200 sec. This exposure time is equivalent to the subsequent time setting for an exposure scale divided into increments of one-third. However, this value is still located within the permitted limits mentioned in DIN 19016[6]. An electronic shutter can be adjusted much more accurately than mechanical shutters. It is remarkable that with cameras which have an electronic shutter, the exposure time is displayed in the Exif data with very precise numbers (e.g., 1/7.5 sec., 1/28 sec., 1/58 sec.). In this case it seems that the indicated exposure time corresponds with the actual shutter time. The measurement of the actual area of the entrance pupil requires more effort than measuring the exposure time and will therefore not be performed. This inaccuracy in shutter adjustment and aperture falsifies the calculated exposure value and consequently the resulting luminance.

4.1.2. Setting of ISO

Defining the ISO speed of digital cameras is similar to the method used to define film speed. The determination of a digital camera's speed is documented in ISO 12232[8]. Each CCD or CMOS sensor has a native speed. This native sensitivity depends on the basic quantum efficiency of the photon-electron conversion process, the physical size of the pixel and depth of the potential well used to collect the electrons. If a higher level of sensitivity is necessary for proper exposure than the original sensitivity of the chip, the electrons stored on the sensor are amplified. This amplification is obtained through an automatic gain controller on the chip[4]. Unfortunately, increasing the sensitivity also amplifies undesired noise. As shown in Section 4.1.6., noise negatively affects the luminance measurement. However, the main problem of achieving reliable results for luminance measurements is attaining a reliable amplification of the signal. That means that the automatic gain control must be carefully calibrated. Should this not be the case, for example an ISO speed of 100 is in reality equivalent to ISO 80, this real value is not indicated in the Exif data. This leads to errors because the result is calculated using an incorrect value.

4.1.3. Constancy of exposure

The constancy of exposure mainly depends on the ability to accurately reproduce the aperture and shutter settings. Apparently, aperture and shutter do not have the exact same exposure time and diameter with exposures taken successively, although the exposures were taken with the same f-number and exposure-time settings. The reason for this is the limited accuracy of mechanical components.

4.1.4. Analog/digital conversion

Image sensors store images in the form of electrons generated by absorbed photons. This electrical charge is converted to a voltage which is amplified to a level at which it can be processed further by the Analog to Digital Converter (ADC). The ADC classifies the continuous values of voltage into a number of discrete numeric digital values. This step inevitably contains data loss and rounding errors, called quantization error. This error can be reduced by enlarging the depth of quantization which is defined by the number of bits. The resolution of an ADC in a digital camera can be determined by the dynamic range of the sensor. The higher the dynamic range is the higher the depth of quantization must be in order to avoid a loss of information. Today most digital cameras are equipped with A/D converters which have resolutions of 10 to 14 bits. After the A/D conversion, a tonal curve is applied to the digitized linear sensor data, so that images viewed on a monitor or in printed form are more pleasing to the eye. To avoid posterization or banding when applying this tonal curve on the linear raw data, the A/D conversion should have a sufficient depth of quantization, such as 12 bit [9]. However, the output data of a JPEG image is only available as an 8-bit image data. Due to the nonlinearly coding of the signal the resolution of 8 bit is sufficient to prevent noticeable contouring for the eye, because the 256 digital values are distributed over the tonal range according to the characteristic of human vision. The A/D converter can be located following different steps in the image processing chain. The first possibility to do so is after converting the raw sensor data. It can also be located some steps later, as with the Nikon D2X, just after the white balancing gain. In this way, the colour channel data are pre-conditioned prior to A/D conversion. This leads to finer gradations and smoother transitions across the colour range. Thus, limited accuracy in measuring luminance can lie in using an incorrectly converted digital output value (e.g., due to rounding errors) for computing the luminance.

4.1.5. White balance

For the measurement of luminance with a digital camera, setting the automatic white balance is the best method for adapting to the perception of the human eye. The chromatic adaption transformation maps the image appearance to colorimetry among different illumination sources. The attributes of scene adopted white, chromaticity and luminance, should be maintained by the transformation[10]. In the case of luminance measurement it is very important to save the perceived luminance of the scene. A manually set white balance removes colour cast too extremely. For example, an object illuminated with tungsten light appears too bluish after the manual application of white balance. This image impression does not correspond with the perception of human eye. The illumination-estimation algorithms for auto white balancing are developed for a good and natural reproduction of a scene, as the eye would see it. Therefore, these algorithms reproduce the scene luminance nearly correctly. (A few tests referring to the automatic white balance can be found in [11].)

4.1.6. Noise

Each step involving sensor-based image formation is affected by noise. Various different noise sources exist. They can be classified as Fixed Pattern noise (FPN) (due to variations in the manufacturing of sensors, each pixel has small differences in sensitivity) and Random noise (e.g., Photon shot noise, Dark current shot noise, Reset noise and Thermal noise). The Fixed Pattern noise does not change significantly from image to image. Thus, it can ideally be removed by taking pictures in absence of a signal and subtract this image from the real image. This step is carried out in the image processing system. Random noise, like the name says, can not be removed as easily as the FPN. The sources of noise depend on certain parameters such as temperature, exposure time and signal. Measuring luminance on a single pixel can result in an error because it is possible that it has the wrong shade. Therefore, to minimize the effect of noise on the luminance measurement, the mean value of several pixels has to be taken for the evaluation.

4.1.7. Colour transformations

In the imaging pipeline of a camera there are two different colour transformations[3]. The purpose of scene-referred colour encodings is to represent the device dependent data in a device independent colorimetric colour space (also named as unrendered colour space) like CIE XYZ or CIE Lab.

This transformation from the RGB data in a camera's colour space to an unrendered colour space is simply linear.

$$RGB_{cam} \xrightarrow{\boldsymbol{M_{3x3}}} RGB_{unrend} \tag{4}$$

Because the camera's response (RGB_{cam}) is non-colorimetric, it is safe to assume that the camera values do not exactly match the values of a colorimetric colour space by a linear transformation. Its linearity is justified with a simpler and efficient implementation in the system. Camera manufacturers are attempting to find an optimal matrix (M_{3x3}) that maps the camera's colour space measurements to a colorimetric colour space in order to achieve a minimal difference between both colour spaces. This operation is usually an approximation and therefore the resulting data (RGB_{unrend}) are not accurately colorimetric. This fact affects the exactness of measuring luminance. Any scene editing is done in this scene-referred image state[4]. Scene modifications include for example the correction of overexposed regions of a backlit scene, or they can include making the grass greener and the sky bluer. Such modifications should be adjustable for the user. If this scene-dependent optimization is done automatically and if users are not able to switch it off, such a camera can not be used as a luminance measure camera, as original scene data are manipulated too much. The second colour process in the imaging chain is known as colour rendering. A colour rendering transformation is used to transform an image in an unrendered colour space to an output referred image. This nonlinear operation embodies a tone and gamut mapping and a colour preference adjustment. Human observers do not care as much for an accurate scene reproduction as they do for a pleasing reproduction of a scene. Large-scale colour rendering algorithms are responsible for this pleasant image, thereby accounting for the preferences of the human observer. (e.g., it is important for human observers to recognize as many details in dark areas as possible. That is why the gamut is different in dark areas than in lighter ones). In most cases the output of this image processing state resembles that of the sRGB colour space. The development of applicable algorithms is very time-consuming, expensive and typically proprietary. So it is completely impossible to convert the rendered data back to the unrendered colour space without knowledge of the rendering transforms used. Sophisticated algorithms can in fact be image dependent and even locally varying within an image[3,12]. On this basis the calculation of the CIE Y value, as explained in Section 3.1, is only an approximation of the Y value. Because users gain no insight in the colour rendering process and the colorimetric adaption of the original device-dependent data is only an estimate, it is not possible to reconvert the output data in exact CIE XYZ values.

4.1.8. Vignetting

The light falling on the sensor is attenuated due to geometric effects. The capture of an off-axis object through a lens is connected with an illuminance fall-off in the peripheral areas of the image. This effect is known as vignetting. There are two sources for this darkening of the image corners: natural vignetting and artificial vignetting. Natural vignetting is inherent to each lens. The wider the off-axis angle α of the object point, the higher the brightness fall-off is on the chip. Therefore, wideangle lenses are most affected by this effect. The decrease in illuminance from natural vignetting is proportional to the fourth power of the cosine of the off-axis angle. Natural vignetting is also known as the cosine fourth law[13]:

$$E(\alpha) = E \cdot cos^4 \alpha \tag{5}$$

Artificial vignetting relates to the fact, that oblique incident light is trimmed by the lens frames. This type of vignetting can be eliminated by stopping down the aperture. Because all lenses are affected by vignetting (some more than others), it is not advisable to measure luminance on the outer edges of an image. It takes into account that those areas, which are to be measured, should not lie on the outer margin of the image[13]. A further kind of vignetting exists that only affects digital cameras, called pixel shading. It is caused because the light-sensitive photodiodes are pressed between walls, which arise from the production of a light-sensitive chip. Therefore, light incident at an oblique angle can potentially not reach the light-sensitive area and additionally the wall casts a shadow on the photodiode. With each lens it is possible to measure the relative fall-off of brightness, depending on the locality on the sensor. This measurement is achieved by taking a photo with an opened diaphragm of a homogenously illuminated frosted glass pane. Here, the worst case of brightness fall-off is measured. The relative deviation from the highest digital value (averaging 64 pixels) is calculated for the remaining digital values (averaging likewise 64 pixels). A tolerable limit for the evaluation of luminance is located at a relative deviation of 5%. The resulting luminance error for this difference of digital values depends on the shape of the characteristic line of each camera. In the region of larger digital values the relative difference in the resulting luminance is higher than in lower digital output values. The value of the resulting luminance deviation depends on the gradation of the OECF curve.

4.1.9. Stray light

Stray light occurs in most image capturing systems. Different factors exist for the origin of stray light in a digital camera. At barriers of two different optical materials a partial reflection of the incoming light arises. In a camera lens, this occurs on the barriers from glass to air. A lens with many lenses (e.g., zoom-lenses) shows a relatively high rate of stray light. The silicon image sensor also has a very high reflection rate as the protection glass installed before the image sensor reflects the incoming light, too. This diffused light strays around in the camera body and lens, reducing the image contrast as a result and therefore negatively affecting the output data for luminance measurement. A method which reduces stray light is the surface-coating of lens elements in a lens and of the surface of an image sensor. During the calibration process the stray light is taken into consideration, but any light of the surrounding field is shielded when measuring the OECF. The whole space of measurement is shaded so that no reflection is possible and the only illumination comes from the back illuminated test chart. Such ideal conditions do not exist when applying luminance measurement to a real scene. Certainly there is a lot of light which is not actually in the field of view, but still falls obliquely into the lens (extreme oblique light can stray at the lens frame). This considerable effect of surrounding light can be minimized by using a lens hood.

4.2. Measurement accuracy

4.2.1. Error of luminance meter

Minolta declares an accuracy error of 2% at an illumination with an illuminant A for the Minolta LS-100 luminance meter. The Gossen MAVO-Monitor claims an error rate of 2.5% at the same illumination. Both devices are assigned to grade B, as is defined in DIN 5032-7[14]. Therefore the total error (including among other things the deviation of V(λ), error of indication, error of linearity etc.) of these devices range from 6% to 10%.

4.2.2. Error of the luminance measurement

Measurements of luminance of the patches from the OECF test chart are tainted with uncertainty. This uncertainty is a random error which describes the repeatability of measurements. It can be reported by calculating the standard deviation of the measurements which characterize the dispersion of the result.

5. CONCLUSION

5.1. Analysis of the measurement results

The results of the camera tests mentioned in Chapter 2 can be found in a more detailed version in[11]. The test with cameras of all categories shows, that a professional camera, like the Nikon D2X, is just as qualified for use as a luminance measure camera as the consumer camera Fuji F10. This result was contrary to expectations. An argument to support this result is, that consumer cameras are equipped with electronic shutters which work very accurately, and it seems too, that the Fuji F10 has an acceptable colorimetric adaptation and fewer further colour renderings similar to the professional cameras.

The resulting luminance values of the cameras are compared with the values of the luminance meters. The deviation of these two values depends on the camera and if coloured objects or only monochrome areas were measured. In some cases, when measuring coloured objects the deviation can be over 30%. These are probably colours which are poorly adapted to the CIE Y value or which can not be reproduced well because of a limited spectral sensitivity of the sensor. These evaluated deviations contain all error sources mentioned in Chapter 4. The errors which most often affect the result are an inaccuracy of exposure data, a wrongly calibrated ISO amplification and the inaccurate adjustment of aperture and shutter time. In measuring colour objects the main error will be an inadequate adaptation of the camera’s data to the CIE Y value and further preferred colour renderings. In addition, a reliable declaration of exposure data in the Exif header is an important criterion as these are the values for computing the luminance.

5.2. Use in practice

The evaluation of the luminance can be done with an MS-Excel file, for example. The user has to enter the RGB output data of the image area which is to be evaluated and the exposure settings of the image which can be received from the Exif data. Using the formulas in Chapter 3, the according luminance is calculated and shown in the MS-Excel sheet as the result. An application which benefits from the advantages of using a conventional camera as a luminance measure camera is the accident examination. The operational area for taking luminance measurements for accident assessors is confined to night accidents. An advantage for this occupational group is that they can present the documentation of their measuring points and results in court in order to prove that the measurement data is indeed correct. The assessor’s measurements can also still be checked after the fact, for example should the case be reopened. In addition to the advantages mentioned in the Introduction (Chapter 1) it has to be mentioned that a digital camera has a measuring angle which is smaller than that of a luminance meter. Most luminance meters have measuring angles of 1°. The minimal measuring angle of a digital camera is limited by the minimal evaluation area of 5x5 pixels (to minimize the effect on noise) and the image scale of the optical image formation. Another advantage over a point-by-point luminance meter is a larger measuring range. The measuring range within an image of a calibrated digital camera amounts to a luminance contrast of about 90:1. This range varies from camera to camera. It depends on the minimum and maximum digital values, which define the lower and upper limit of the digital values for each channel. However, the whole possible measuring range is larger than that of a conventional luminance meter. The selection of a measuring range is defined by the settings for integration time, aperture and ISO speed. Accident scenes can also have high luminance contrasts, for instance if there is a very bright headlight and a pedestrian with dark clothes, which stands out of the headlight. Therefore, the user has to make several exposures to evaluate such a wide luminance range.

To use a digital camera as a luminance meter one has to consider that these cameras are not exact measuring instruments. Digital still cameras are constructed with a main focus on getting pleasant pictures out of the camera. However, for many applications the luminance results of a digital camera will be sufficient. There are measuring tasks which do not need the absolute luminance value but, for example, the luminance distribution in the whole scene or luminance ratios.

REFERENCES

1. ISO 14524: 1999, Photography - Electronic still-picture cameras – Method for measuring opto-electronic conversion functions (OECFs)
2. ISO 2721: 1982, Photography – Cameras – Automatic controls of exposure
3. ISO 22028-1: Photography and graphic technology – Extended Colour encodings for digital image storage, manipulation and interchange – Architecture and requirements
4. R. Ramanath, W. Snyder, Y. Yoo, M. Drew: "*Color Image Processing Pipeline"*, *IEEE Signal Processing Magazine*, vol.22, no.1, p.34-43, 2005
5. IEC 61966-2-1: 1999, Colour management – Default RGB colour space – sRGB
6. DIN 19016: Zeitmessung an Schlitzverschlüssen; Begriffe, Belichtungszeiten, Messanordnungen, Synchronkontakte, Dezember 1984
7. DIN 4522-1: Aufnahmeobjektive; Blendenzahlen und Grenzwerte, März 1991
8. ISO 12232: 1998, Photography – Electronic still-picture Cameras – Determination of ISO speed
9. S. Puglia, *Handbook for Digital Projects*, Technical Primer (chapter VI), First Edition, North East Document Conservation Center, Andover, Massachusetts, 2000
10. J. Holm, "*Adjusting for the Scene Adopetd White"*, *IS&T's 1999 PICS Conference*, p. 158-162, 1999
11. H. Gabele, "*The usage of digital cameras as luminance meters*", Diploma Thesis, Faculty of Information, Media and Electrical Engineering, University of Applied Sciences Cologne, Institute of Media and Phototechnology, Cologne, February 2006
12. S. Süsstrunk, R. Buckley, S. Swen, "*Standard RGB Color Spaces"*, *Proc. IS&T/SID's 7th Color Imaging Conference*, p. 127-134, 1999
13. G. Schröder, *Technische Fotografie*, Vogel-Verlag, Würzburg, 1. Auflage, 1981
14. DIN 5032-7: Lichtmessung, Klasseneinteilung von Beleuchtungsstärke -und Leuchtdichtemessgeräte, Dezember 1985