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# Influence of the Light Source on the Image Sensor Characterization according to EMVA 1288

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## Abstract

*Due to the increasing demand of machine vision applications in a variety of scenarios, it is necessary to know the capability of the hardware before implementing it. The EMVA 1288 standard by the European Machine Vision Association aims to provide a basis to compare the performance of cameras based on a characterization of the image sensor, using a monochrome light source. The purpose of this paper is to investigate the influence the light source has on the measurement results. Which parameters are dependent on it, and which are not? Are there any benefits to using a broadband light source? To answer this question, a series of measurement runs using six different illuminants were performed with the same camera. The illuminants included monochromatic blue, green and red light as well as three different white spectra (CIE E, CIE D65 and white LED). The results show that the influence of the light source on the metrics is limited to the measured quantum efficiency of the camera and related parameters. As a consequence, using a non-monochromatic light source for the measurements should be an available option, as it can provide better insight into use-case specific performance and improve comparability.*

## Introduction

The amount of machine vision applications is steadily on the rise, no matter if it is to detect traffic signs in a car or to guarantee quality in a production line. In order to achieve the best possible results, it is important to know which camera to use. To make the comparison and choice easier, various standards for sensor and image quality exist. The EMVA 1288 standard is one of those standards, and aims to provide a "unified method to measure, compute and present specification parameters and characterization data for cameras and image sensors"[1]. The method of the EMVA 1288 standard requires the use of a narrowband light source with a peak wavelength close to the camera's highest spectral response for the measurements. While this approach is suitable when comparing cameras for the use in a controlled environment, it raises the question of comparability for other use-cases like automotive.

## Concept

This paper aims to analyze the impact of using broadband light sources has on the final results of the EMVA 1288 measurements. Which parameters are influenced by the light source, which are not? Are there any side effects that can occur? What are the benefits from this approach? Using non-narrowband light sources for measurements according to the EMVA 1288 standard creates the problem of counting the photons that are hitting the pixels. The official approach is to use a calibrated photodiode that measures the absolute irradiance in the sensor plane. Because of the narrow bandwidth, the number of photons per area and time can be calculated from that with sufficient accuracy using the following equation [2]:

$$N_p[photons] = 50.34 \cdot A\left[\mu m^2\right] \cdot t_{exp}[ms] \cdot \lambda[\mu m] \cdot E\left[\frac{\mu W}{cm^2}\right]$$

with:

$$\begin{aligned} A &= \text{pixel area} \\ t_{exp} &= \text{exposure time} \\ \lambda &= \text{peak wavelength of light source} \\ E &= \text{irradiance} \end{aligned} \tag{1}$$

The constant 50.34 originates from the reciprocal product of the speed of light $c$ and Planck's constant $h$ adjusted to units suitable for image sensors.

Using a wider band light source would increase the error, as the energy of a photon is directly related to its wavelength. To circumvent these limitations, a calibrated spectrometer is used for the irradiance measurements in this paper, providing very accurate irradiance measurements in $\mu W/cm^2/nm$. This allows to compute the number of photons for any light source with an adapted version of Eq. 1:

$$N_p[photons] = 50.34 \cdot A\left[\mu m^2\right] \cdot t_{exp}[ms] \cdot \sum_{i=1}^{n} \cdot \left(\frac{E_i + E_{i+1}}{2}\left[\frac{\frac{\mu W}{cm^2}}{nm}\right] \cdot (\lambda_{i+1} - \lambda_i)[nm] \cdot \frac{\lambda_i + \lambda_{i+1}}{2}[\mu m]\right) \tag{2}$$

with:

$$\begin{aligned} i &= \text{measurement channel of the spectrometer} \\ n &= \text{number of selected measurement channels} \end{aligned}$$

## Method

In order to perform the necessary measurements, a modular measurement setup suitable for tests according to the EMVA 1288 standard was constructed. It consists of a large plastic tube with a mount for the camera on one end, and mounts for the light sources on the other, as illustrated in Fig. 1. The light sources used were a green LED, a white LED light source (phosphor-based) and a multi-spectral LED light source. With this setup, a series of measurement runs using 6 different illuminants (red, green (Cree), blue, CIE D65, CIE E and white LED (VEGA)) with 10 runs per illuminant was performed with a monochrome industrial camera as the device under test (DUT). To validate the

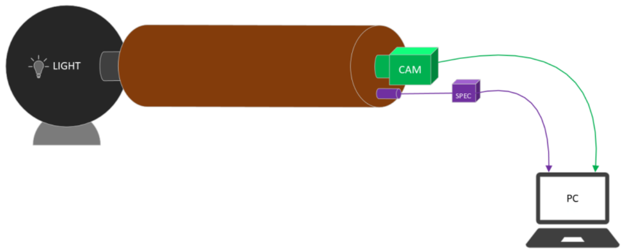


***Figure 1.*** *Schematics of the measurement setup*

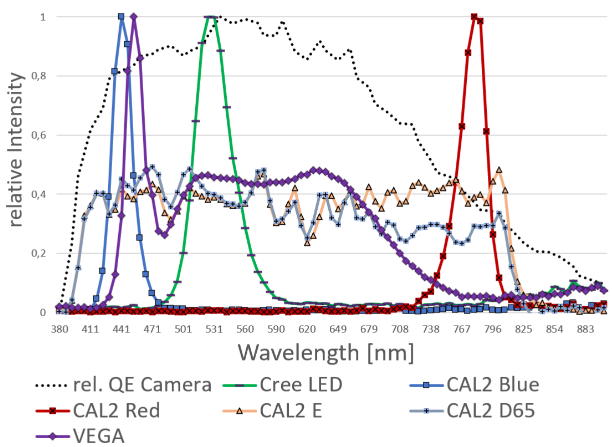


***Figure 2.*** *Quantum efficiency of the camera vs spectra of the illuminants (D65 and E not normalized to 1 to increase legibility)*

setup, measurements with the green LED were compared to an EMVA 1288 report published by the manufacturer of the DUT [4]. The spectra of the illuminants can be seen in Fig. 2. An ordinary measurement run according to the EMVA 1288 standard includes 4 sets of images. Two sets to identify spatial nonuniformities (one with illumination, one without) and two to identify temporal noise and linearity (one with illumination, one without):

1. **Bright (temporal):** $\geq$ 50 equally spaced exposures ranging from min. digital gray value to max. digital gray value (2 images per exposure)
2. **Dark (temporal):** 2 images per exposure time used in (1)
3. **Bright (spatial):** $\geq$ 100 exposures at 50% of the max. digital gray value (1 image per exposure)
4. **Dark (spatial):** same amount of exposures at the same settings as used in (3)

This amounts to a minimum of 400 images taken for one measurement run. For the measurements in this paper, the amount of exposure steps for (1) and (2) was doubled for better accuracy, resulting in 600 images per run. The camera settings were left as close to the factory settings as possible, only adjusting the black offset to account for negative noise. The irradiance of the sensor was varied by changing the exposure time and leaving the light sources at a constant illumination level. To be able to compute the number of photons irradiating the sensor, an absolute calibrated spectrometer was used instead of a photodiode as proposed in the standard. The measurements from the spectrometer were used to calculate the number of photons hitting the pixels using Eq. 2. The resulting images and data were then analyzed using the EMVA reference implementation published on GitHub[3]. It generates the results and graphs for an EMVA 1288 report from the image-data and the corresponding information about exposure-time and photon-count. At the time of writing, the reference implementation had not yet been updated for release 4.0 of the EMVA 1288 standard, but was still programmed according to release 3.1. However none of the changes for release 4.0 have any significant influence on the measurements discussed in this paper.

## Results

The results indicate that the influence of the light source on the metrics is limited to the measured quantum efficiency of the camera and related parameters. Other parameters like dynamic range, signal to noise ratio, system gain, linearity, nonuniformities and dark noise remain consistent throughout the measurements with different light sources. This is also shown in the progression of the SNR and photon transfer curves which stay consistent throughout the different light sources. Exemplary graphs can be seen in Fig. 3 and Fig. 4. The measured quantum efficiency using the different illuminants of course relates closely to the spectral distribution of the irradiation compared to the spectral sensitivity of the DUT. This is visualized in Fig. 2. The CIE D65 and CIE E spectrum mainly differ in the amount of red and NIR irradiation. As the camera is less sensitive to this kind of irradiation, the D65 spectrum yields a higher quantum efficiency. In the overview (Fig. 5) it can also be observed that the differences in quantum efficiency are rather small, as long as the majority of the irradiation is within the DUT's spectral range. The white LED still reached over 60% quantum efficiency, which is close to the DUT's maximum quantum efficiency.

The fact, that monochromatic blue light yields a higher quantum efficiency in the final results than the monochromatic green light is unexpected. According to the quantum efficiency measurements seen in Fig. 2 as well as in the report from the DUT-manufacturer, the camera's quantum efficiency should be lower for the blue light at 441nm than for the green light at 527nm. This contradiction can not be explained at this point as preliminary runs with the blue illuminant resulted in a quantum efficiency lower than that of the green LED (60.9%).

An overview of all the results can be seen in Fig. 6. The high values for the dark current measurements can be attributed to the DUT's automatic and erratic black level clamping, which could not be disabled.

## Conclusion

Since parameters related to the quantum efficiency are the only metrics in the EMVA 1288 standard that are directly influenced by the change of illuminant, one could arguably perform the test procedure with a multitude of light sources if the camera's maximum quantum efficiency is not of interest. Also the approach of using a calibrated spectrometer instead of a calibrated photodiode proved to be suitable to compute the number of photons irradiated by the light source, while giving more flexibility in the choice of illuminant. The inconsistency of the measurements, regarding the quantum efficiency, may be avoided by using a different (type of) spectrometer, actively stabilizing the temperature of the spectrometer, or by keeping

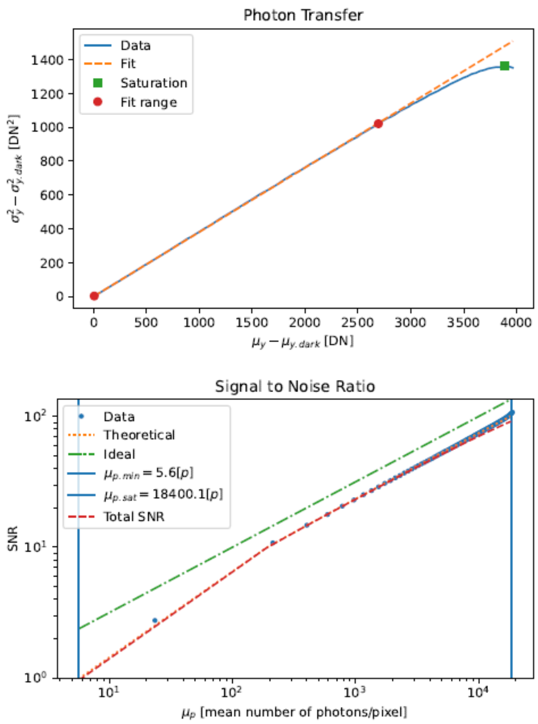


***Figure 3.*** *Exemplary Photon Transfer and SNR curves of the CIE E spectrum*

a calibrated photodiode for reference, which was not possible for this study. Generally, the white light sources yielded a higher quantum efficiency than expected, only deviating from the maximum by at most 10%. There are many advantages to using a non-monochromatic illuminant however. The CIE E illuminant for example would provide an equally distributed irradiance across the visible spectrum, resulting in an ”average case” scenario that would make comparisons between cameras more equal.

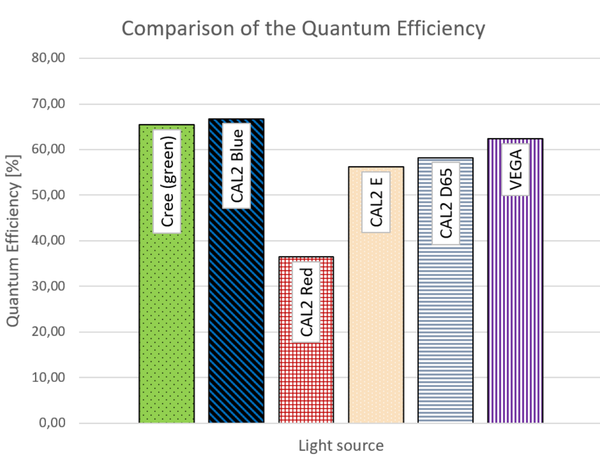


***Figure 5.*** *Quantum efficiency of the different illuminants*

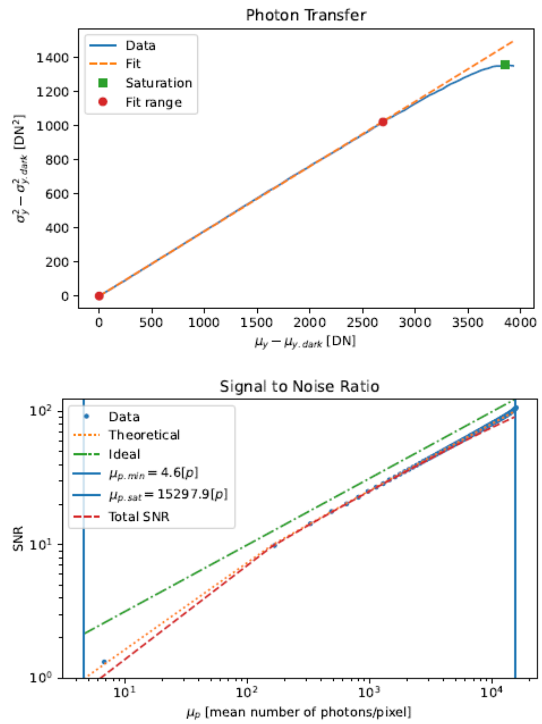


***Figure 4.*** *Exemplary Photon Transfer and SNR curves of the green LED*

## References


[1] EMVA 1288 Working Group,”EMVA Standard 1288 - Standard for Characterization of Image Sensors and Cameras (Release 4.0 Linear)”, 2021

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## Author Biography


*Ganesh Kubina studied Media Technology at the University of Applied Sciences in Cologne, specializing in camera technology and image processing. He received his B.Sc. in 2022 and has been working as an Image Quality Scientist at Image Engineering, an independent test lab for imaging devices and manufacturer of test equipment, since then. His personal interests include digital and analog photography, travelling and coffee.*

| Parameter | Unit | Cree | | CAL2 Blue | | CAL2 Red | | CAL2 E | | CAL2 D65 | | VEGA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dynamic Range | Bits | 11,73 | 0,3% | 11,71 | 0,2% | 11,70 | 0,3% | 11,66 | 0,2% | 11,67 | 0,2% | 11,70 | 0,2% |
| System gain | | 0,38 | 0,0% | 0,38 | 0,0% | 0,38 | 0,0% | 0,38 | 0,0% | 0,38 | 0,0% | 0,38 | 0,0% |
| Quantum efficiency | % | 65,41 | 1,1% | 66,78 | 0,8% | 36,55 | 1,8% | 56,18 | 0,9% | 58,24 | 1,0% | 62,33 | 1,1% |
| Responsivity | | 0,25 | 1,1% | 0,25 | 0,8% | 0,14 | 1,8% | 0,21 | 0,9% | 0,22 | 1,0% | 0,24 | 1,1% |
| Maximum SNR | | 100,72 | 0,2% | 100,54 | 0,3% | 100,92 | 0,3% | 100,87 | 0,3% | 101,10 | 0,2% | 101,05 | 0,2% |
| Dark Current from mean | $e^-/s$ | -6,73 | -95,4% | -17,91 | -29,7% | -11,64 | -50,9% | -85,53 | -10,8% | -88,26 | -13,2% | -104,65 | -23,7% |
| Dark Current from variance | $e^-/s$ | 39,22 | 60,4% | 44,12 | 14,1% | 39,30 | 54,7% | 30,53 | 42,3% | 21,08 | 76,8% | 91,36 | 49,2% |
| Max Linearity error | % | 0,87 | 19,7% | 0,90 | 12,4% | 0,94 | 15,9% | 0,85 | 22,2% | 1,00 | 19,3% | 0,90 | 16,2% |
| Min Linearity error | % | -0,43 | -7,0% | -0,44 | -7,8% | -0,45 | -9,7% | -0,45 | -9,1% | -0,46 | -16,6% | -0,42 | -9,9% |
| Temp.Dark Noise $\sigma_d$ | $e^-$ | 2,38 | 3,8% | 2,39 | 2,2% | 2,45 | 3,3% | 2,53 | 1,8% | 2,53 | 2,4% | 2,46 | 2,6% |
| Temp. Dark Noise $\sigma_{y.dark}$ | DN | 0,95 | 3,4% | 0,96 | 2,0% | 0,98 | 3,0% | 1,01 | 1,7% | 1,01 | 2,2% | 0,98 | 2,3% |
| Absolute sensitivity threshold | Photons | 4,58 | 3,3% | 4,51 | 1,7% | 8,38 | 2,8% | 5,59 | 1,2% | 5,40 | 1,7% | 4,94 | 2,2% |
| Saturation Capacity | Photons | 15513,11 | 1,5% | 15138,05 | 0,8% | 27874,48 | 1,9% | 18114,88 | 1,1% | 17550,21 | 0,9% | 16383,01 | 1,1% |
| DSNU | $e^-$ | 2,10 | 8,8% | 2,78 | 3,4% | 2,21 | 14,2% | 0,77 | 3,6% | 0,77 | 1,2% | 0,70 | 3,4% |
| PRNU | % | 0,46 | 0,0% | 0,50 | 0,0% | 0,49 | 0,1% | 0,45 | 0,0% | 0,45 | 0,0% | 0,45 | 0,0% |
| | | Mean | StdDev | Mean | StdDev | Mean | StdDev | Mean | StdDev | Mean | StdDev | Mean | StdDev |

***Figure 6.*** *Measurement results (mean and standard deviation over 10 Runs)*