Verification of light-source uniformity in a portable setup for digital camera characterization

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Abstract — This work presents a flexible, low-cost and portable setup that allows the characterization of digital cameras based on the EMVA 1288 standard. Instead of using expensive equipment as an integrating sphere, we propose a properly evaluated simple light source based on a translucent glass surface. To make this possible it is necessary to understand the uniformity aspects of this surface and to map its interference by means of a characterization procedure. The method proposed basically subtracts the non-uniformity map of the original light source allowing its use as a flat field surface. An optical setup was developed to extract data for the uniformity verification. It is basically composed by a digital camera, a frosted-surface light source, an extension tube and a translation stage. Some preliminary results are presented showing the validity of this approach.

***Keywords* — EMVA1288, standardization, translucent surface, uniformity, homogeneity, characterization, digital cameras, flat-field luminance**

Introduction

In the past two decades the use of digital cameras has experienced a large growth both in scope and in volume. Its rapid availability on the market, however, outpaced any early attempt of standardization of the specifications, which left manufacturers at their own convenience to test and present results on a datasheet. This limits severely a judicious cross comparison between cameras of different brands and sometimes even of different models. In 2004 a standardization working group driven by industry and user oriented was founded to help sensor and cameras manufacturers and costumers to deal with choice of camera work. A standard EMVA 1288[1] was created to provide a concise description of how to characterize a camera and uniformly publish the results.

Camera characterization is a method to evaluate quality and sensitivity of a camera by matching a mathematical model of the camera to measurement data [1]. The procedure involves a number of steps in dark and for different exposure conditions. The setup required by EMVA 1288 to extract most of the camera data demands that the sensor is illuminated by homogeneous light (flat field) in order to create the so called flat-field frame. Most camera sensor manufacturers, who adopt this standard, use a usually expensive Lambertian surface (e.g.: integrating sphere) to achieve this uniform luminance from the source. The commonly assembled setups for this purpose are versatile but also bulky, which require that the camera to be tested is brought to the setup.

We aim at a portable low-cost setup that can be attached to the camera in its operational location, enabling *in situ* characterization within its operating environment. Spectrally characterized high-luminance LEDs can be used at one end of an opaque tube, within which a series of parallel translucent surfaces can be positioned. This assembly will be referred henceforth as 'characterization tube'. At the other end of the tube the camera is attached. For the evaluation, in this paper we use a laser beam through a 2.4mm aperture and diffracted by an iris, impinging thereafter on a set of circular frosted glass flats [2]. We varied the number of flats from one to eight to find the optimal number for this application; they are located at 5mm from each other and within a C-mount metal tube with dark inner walls. The length of the tube complies with that specified by the EMVA 1288 standard. The method to measure the uniformity achieved on the sensor surface will be presented along with the results.

Objectives

The goal of this paper is to validate the feasibility of using the characterization tube to characterize digital cameras according to the EMVA 1288 standard. Therefore, a method has been developed to verify the uniformity of the light source that is to be used to illuminate the image sensor of the digital camera to be characterized. This calibration procedure is to be done for every characterization tube before the actual camera characterization is carried out. Light-intensity non-uniformities will be converted in a fixed error image that will be used as a reference to measure the quality of the results of the characterization.

To verify the behavior of results and to find the optimal number of flats, the number of surfaces varies in a series of tests from one to eight units. Additional flats are always included in parallel to the previous ones, keeping the distance between them close to 5mm. The distance from the closer surface to the image sensor is always the same.

The tube diameter is as same as the camera aperture diameter and features a C-mount thread allowing direct fixed coupling to the camera case.

Since the response of each pixel in the image-sensor chip can be slightly different, denoted as PRNU (photo-response non-uniformity), the raw data from a single full shot of the camera is not completely reliable in estimating whether the illuminance on the sensor is actually uniform. Therefore, we decided to use the average signal of an array of 6x6 central pixels at each location mechanically scanned within the target illuminated area. This avoids that PRNU affects the uniformity verification.

METHODS AND DISCUSSION

A Sony 1/3" progressive scan CCD, Color/BW, with a 12 bits A/D [3] converter was used to scan the target area. The camera settings were kept fixed throughout the experiments and the imaging-chip temperature was monitored to be 36.9±0.1°C (i.e. 309.1±0.1K). The camera was positioned at a small distance from the end of the tube opposite to the light source and attached to x-y motorized translation stages along 49.05±0.01mm and 26.70±0.01mm for the horizontal and vertical ranges [4], respectively, and 1.25μm-step resolution. During the scan 10,191 images have been collected, distributed in the 43 lines and 79 columns, with three images per step.

The scan was performed eight times, for each of a new flat was included. The setup is shown in Fig.1, where the light source is a 25-mW 532-nm semiconductor laser and the black box is the tube with the flats included. The tube has an internal diameter of (25.17±0.02) mm and a length of 200mm plus 5mm per added frosted glass flat on its respective C-mount.

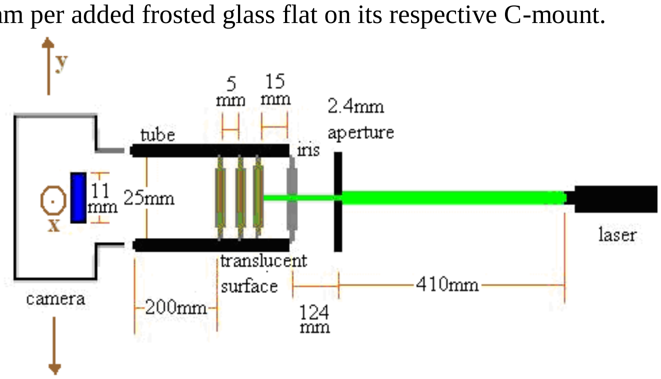
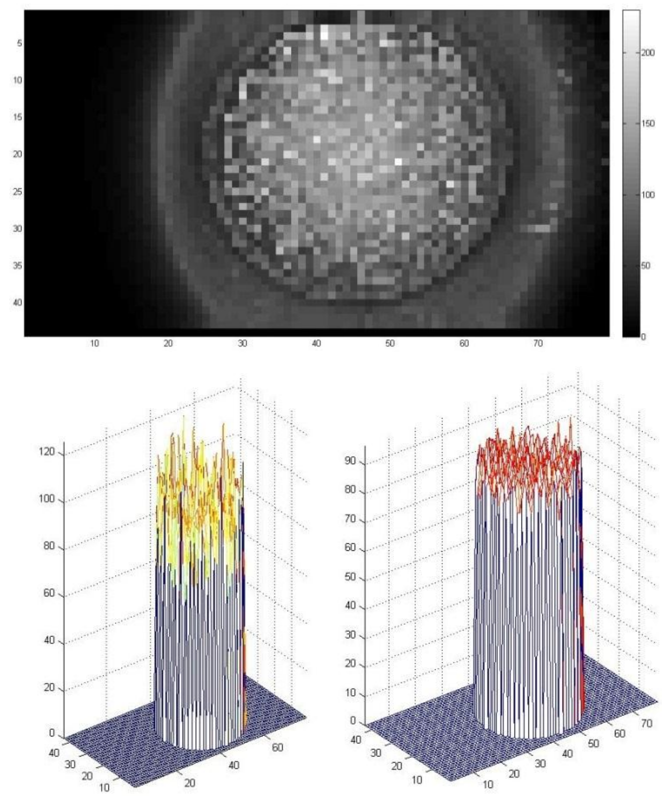


Fig. 1: Setup including camera, characterization tube and light source, where distances are not drawn to scale.

At each translation, horizontal or vertical, the translation-stage commuted (620,91±1,25)μm, stabilized for 2000ms and was followed by an image shot from the camera. Therefore, was generated a set of images mapped according to the position where the photo was taken. From each picture the average of the 6x6 central pixels was taken, and the value included in another matrix. The resulting map of averaged digital numbers corresponds to a map of the respective light intensity on the imager plane over the whole tube aperture, as shown in Fig. 2.

The choice of a 6x6 central matrix was meant to avoid PNRU, besides minimizing possible problems in specific pixels. Three images were taken from each location, increasing the signal-to-noise ratio (SNR) by $\sqrt{3}$, minimizing temporal noise.



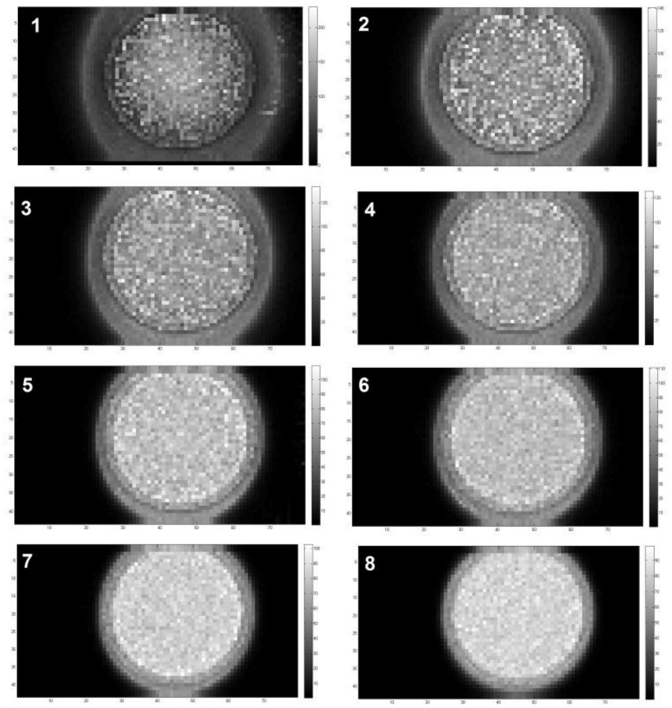


Fig. 2: a) Map of digital numbers (DN) for three flats corresponding to light intensity on the sensor plane over the characterization-tube aperture. The black circle with black dots indicates the tube internal diameter. b) Light intensity received by the central pixel at each position. Right image is for three flats and left image for eight flats. c) All the Maps of digital numbers (DN): the number in the image indicates the number of flats.

The x-y axes represent the position of the central pixel during the camera scan and the z axis represents the intensity of the light received by the pixel at its respective position, in digital number. It can be seen that there is an attenuation of the light intensity close to the edge of the circle; this is a result of the small space between the camera and the characterization tube, where there is diffraction of the incoming light. However, it can be disregarded as the region of interest is close to the center of the circle, where the image sensor to be later characterized will be located.

The non-uniformity map shows the characteristics of light intensity on the output aperture of the characterization tube. That helps to separate the artifacts of light inhomogeneity from those of fixed pattern noise. A limitation might be the rotational angle of the tube when attached to a given camera to be tested. Identification marks both on the tube thread and on the last glass flat can minimize misalignment. This solution enables one to correlate the map orientation to the image collect by the camera.

In a computer program, using the equations 1, 2 and 3 it was possible to calculate the mean, standard deviation and the error. These values are useful to analyze the quality of the camera characterization, i.e., to check how exact are the values that are going to be found.

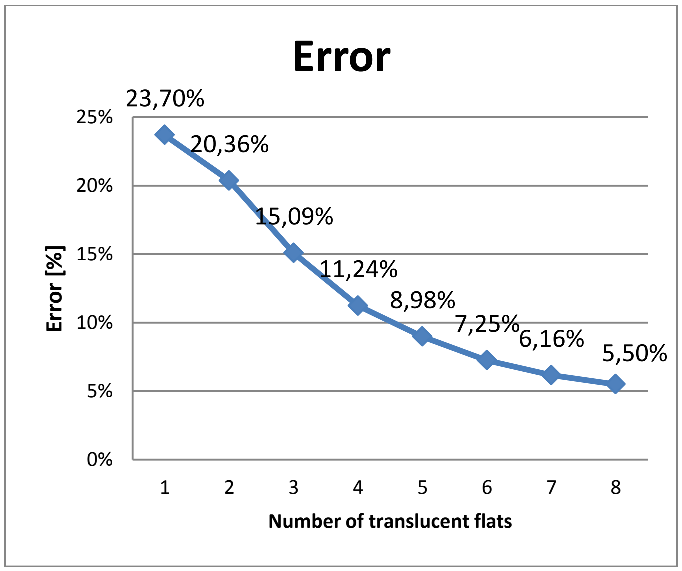
$$\mu_y = \frac{1}{MN}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} y[m][n] \quad (1)$$

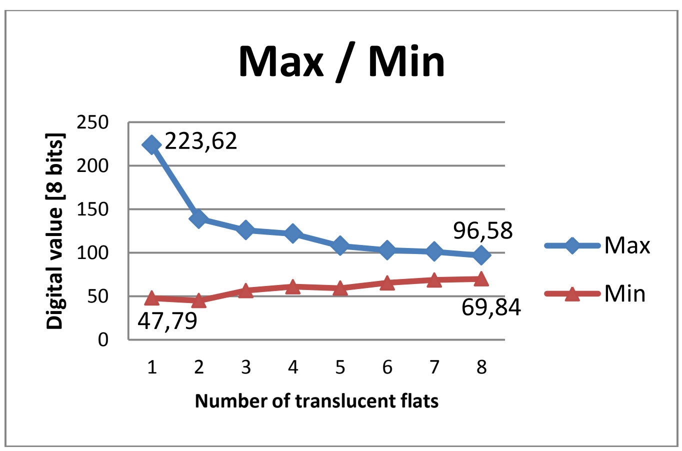
$$s_y = \sqrt{\frac{1}{MN-1}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}\left(y[m][n]-\mu_y\right)^2} \quad (2)$$

$$error = \frac{s_y}{\mu_y} \quad (3)$$

μ_y: mean number of light intensity at sensor plane [DN]
s_y: standard deviation of the light intensity at sensor plane [DN^2]
M: number of columns of image [1]
N: number of rows [1]

In order to use the equations above it is necessary to define the exact area to be analyzed. Therefore, it was measured with a high precision caliper the exact distance between each pixel of the non-uniformity map, which was 620.9±75.5 µm. The output image of the tube features considerable diffraction effects around its edges. A proper non-uniformity map requires that this image is annularly cropped to avoid taking into account edge diffraction artifacts. All the values obtained can be seen in Fig. 3.





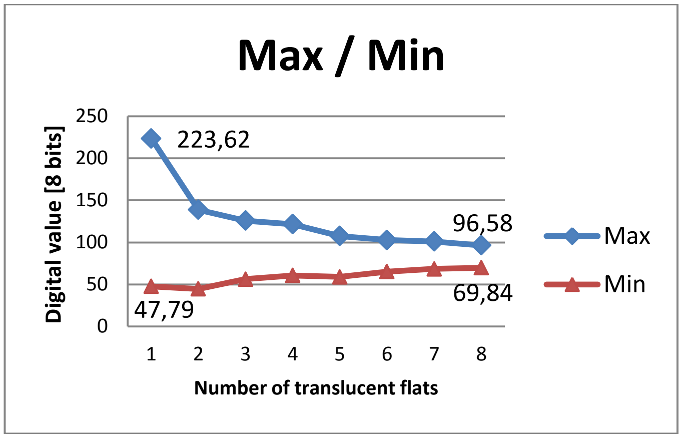


Fig. 3: a) Error vs. number of flats. b) Mean and Standard Deviation vs. number of flats. c) Point of maximum and point of minimum vs. number of flats

The graph shown in Fig. 3a shows a constant decrease in error. It occurs as a result of a faster decrease in the standard deviation of the light intensity, Fig. 3b. In Fig. 3b it is shown the variation of the mean and the standard deviation according to the number of flats, and the expected result was that the mean falls steadily and the standard deviation increases. The mean shows a higher value for seven and eight flats, compared to the result for six. However, analyzing the relative error, the result is still in a valid range (6.16% for seven flats and 5.50% for eight flats). Analyzing Fig. 3c it can be seen the maximum and minimum value found in the map are clearly converging to a common value, indicating that the inclusion of new flats avoids abrupt changes in the map, as expected.

In the experiments up to 8 glasses were used, and the homogeneity error was presented in Fig. 3. The light homogeneity for a larger number of glasses can be estimated by means of a fit function. An exponential curve fit ignoring the first point seems to be more sensible to that purpose and is shown in Fig. 4. The homogeneity error can only reach 4%, closer to the 3% recommended by EMVA 1288 standard, if the number of flats is increased to 16, which would basically double the tube length, once each flat added results an increase of 5mm on the tube length. We believe that 5% inhomogeneity is acceptable provided the calibrated output image is duly aligned to the image sensor under test.

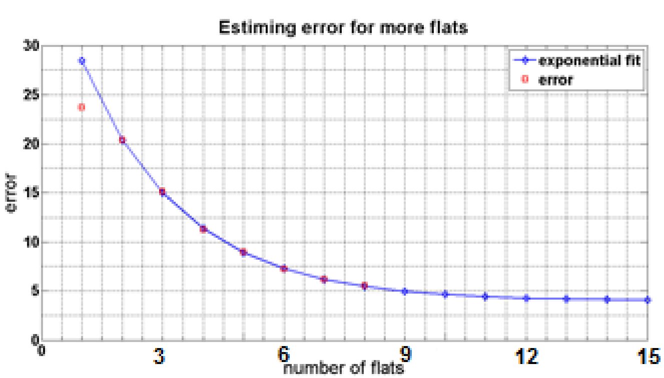


Fig. 4: Error estimated by exponential fit vs. number of 15 flats.

CONCLUSIONS

In the physical characterization of digital cameras according to the EMVA 1288 standard a simple and economic yet satisfactory technique to homogenize the light intensity on the image-sensor plane relies on the usage of a number of spaced translucent surfaces placed inside an opaque tube and in front of a light source with non-homogeneous luminance. Despite its efficiency, some degree of non-uniformity still persists. In this paper we used a digital camera to mechanically scan the light field within the characterization tube aperture and register a non-uniformity intensity map.

Eight non-uniformity intensity maps have been found, each relative to one specific number of flats. The best result was achieved with eight surfaces, featuring a non-uniformity close to 5.5%, a value not so good as those for integrating spheres. Integrating spheres with a diameter of 8 inches provide output light with 1% to 2% non-uniformities, but their dimensions are larger and cost around US$2,000[5]. There are smaller models of sphere, but reducing the size is a tradeoff with uniformity need. The 2 inches cost US$1,500 and have a worst uniformity comparing with that of 8 inches. The characterization tube is smaller and costs around US$100.

The value of non-uniformity can be used as a measurement of the quality of the camera characterization. To improve the results it is possible to perform the light source characterization with 10 translucent flats to achieve 4.5% homogeneity error. With proper tube-camera alignment, this value yields results compliant with those expected by the EMVA 1288 standard.

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