LUMINANCE CALIBRATION OF THE NIKON COOLPIX 990 DIGITAL CAMERA. APPLICATION TO GLARE EVALUATION.

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ABSTRACT

In this paper, we present the luminance calibration of the Coolpix 990, a digital camera made by Nikon. We test the different settings of the camera and choose which ones will be adapted to the calibration procedure. We characterize the projection resulting from the fish-eye lens made by Nikon for this camera. After this, the procedure and the experimental set-up used to calibrate it are detailed. We show how we used both an artificial sky and a sky luminance scanner to allow the calibration on the all EV (Exposure Value) scale. We explain why the luminance is an exponential function of the lightness of the pixel, the lightness being the L* component of the pixel value expressed in the CIE Lab color space; the coefficients of this function depending on the speed and the aperture used to take the picture. We conclude with the different applications in which the Coolpix 990 could be used.

KEYWORDS

Light measurement, luminance mapping, CCD cameras, glare, UGR.

I. INTRODUCTION

For several years, researchers have looked for a fast and easy way to produce luminance maps in order to evaluate visual comfort or to study sky conditions. More than 25 years ago, Hopkinson (1966) and Nakamura (1975) had suggested methods to produce luminance values from black and white prints. In the middle of the 1980s, the first CCD cameras appeared. A CCD (Charge Coupled Device) is an integrated circuit with photosensitive cells. Each cell produces an amount of electricity, which is proportional to the amount of light it receives. The electricity produced by each cell is amplified and used to produce a video signal or a digital image. CCD cameras improved the accuracy of the film-based methods by removing all the inaccuracies due to the chemical treatment of the film. From 1985 to 1995, more than 20 "video-luminance-meters" based on CCDs were developed around the world (Berrutto, 1995).

Since 1992, the authors and their colleagues have tested various CCD based systems: two video cameras (Sony CC F375 E, Sony CCD TR81), a security camera (Hitachi, KP 140) and two digital cameras (Electrim EDC-1000 HR and Nikon E2). The results of these tests have been described by Berrutto (1995). They showed that CCD cameras could predict luminances with 10% accuracy. This accuracy could only be obtained if the shutter speed and the diaphragm aperture were the only parameters affecting the CCD output. The quality of the CCD was different from one camera to the other, at high luminance values some of these cameras created an important "blooming" effect: the saturated pixels affected the adjacent pixels. Even the most accurate systems (Electrim EDC-1000 HR and Nikon E2) were expensive (more than 15,000 €), heavy (more than 3 kg) and cumbersome (with a permanent link to a computer).

During the last five years, CCD cameras have finally become more affordable, much smaller and their quality has increased. This is why we decided to study the capabilities of the recent generation of CCD cameras with the objective to produce luminance maps easily, at an affordable price.

II. THE NIKON COOLPIX 990

II.1 Key Features

We have decided to work with the Nikon Coolpix range of products because of the price of their cameras (around 1000 €: less than a luminance meter) and because they can all be fitted with a fish eye lens (model FC-E8 at a cost of about 300 €). We realized a first calibration with two evolutions of the same camera: the Coolpix 950 and 990, but we finally chose to go deeply into the study of the most recent model. Thus, this paper only describes the developments allowed by the Coolpix 990. Its CCD is a 3.34 Million pixels sensor and delivers images with a resolution of 2048 by 1536 pixels.

Figure 1: The Nikon Coolpix 990 and the fish eye lens FC-E8 used in this study.

The Coolpix saves the pictures on a compact flash card as TIFF or JPEG files. In this last saving mode, using the normal compression rate (1/8), each JPEG file takes about 1 Mo. Since CompactFlash™ cards are available at sizes up to 128 Mo, the Coolpix can hold around 130 images saved using the normal compression rate. This means that you can take the Coolpix on the road and process the images back at your office.

The Coolpix saves images using an extension of the TIFF format called EXIF for Exchange Image File. This format allows to save with the image, extra information such as: date, time, aperture, speed… With previous digital cameras, it was necessary to remember the speed and the aperture used for each picture. Now, this is stored with the image.

Through a set of menus presented on the liquid crystal display of the camera, various parameters can be set: the principle ones are the exposure mode, the white balance and the sensitivity. Behind these menus, there is an operating system software that Nikon calls "firmware". The firmware can be updated by Nikon to add new functionality to the camera. This means that, with the permission of Nikon, we could program it to behave the way we want. By now, we haven't used this possibility, but Nikon recently put a development kit at our disposal in this prospect.

II. 2 Settings

The Nikon Coolpix 990 allows the choice between four different settings for the exposure. The most flexible one is the manual mode: you can set both the aperture and the speed. You can also choose to have one of these parameters, or both adjusted automatically by the camera. The Coolpix 990 uses nine apertures: *f*/2.5, *f*/2.8, *f*/3.1, *f*/3.5, *f*/4.4, *f*/4.9, *f*/5.5, *f*/6.2 and *f*/7, and a continuous range of speeds going from 1/1000 to 8 seconds. As mentioned previously, we need to know the exposure setting for each picture to use the camera as a video luminance-meter, but this is not a strong limitation now that speed and aperture are saved with the image in the EXIF file.

Like all CCD cameras, the Coolpix has a white balance setting and the image produced depends quite a lot on it. To avoid any problem in the calibration, we decided to select a fixed setting. We took pictures of various indoor and outdoor scenes, with various settings of the white balance. We selected the "sunny" setting as being the one which lead to the best results under all conditions.

One of the great advantages of the Coolpix is that it can be fitted with a fish eye lens, which allows a 180° representation of a scene centered on the optical axis of the digital camera. It projects this 3D scene as a circle on the plane of the CCD. The type of projection it uses depends on the fish eye lens. In order to determine it, we mounted the digital camera at the center of a gonio-photometer and moved a collimated light source around it. The type of projection we found is said equidistant: the distance from a pixel to the center of the projection circle is proportional to the angle between the point represented by this pixel on the scene and the optical axis.

Once checked all the setting possibilities and their influence on the photographs, the Coolpix 990 seemed to be a good candidate for the production of luminance maps.

III. THE LUMINANCE CALIBRATION

III.1 Principle

The quantity of light, which reaches the CCD, is proportional to the aperture and to the time during which it was opened. At a constant focal length, the aperture is proportional to the square of its value: $1/f^2$. Calling v the shutter speed, the quantity of light reaching the CCD is proportional to v/f^2. Therefore, if the sensitivity and the gain are constant, the information provided by the CCD only depends on this ratio. In order to give a “name” to each light level taken by the digital camera, we chose to refer to the Exposure Value (EV) scale. This scale is frequently used in the photography or metrology fields, and depends on the v/f^2 ratio:

$$EV = 3.32 \log (f^2/v) \quad \text{(Eqn. 1)}.$$

Since the shutter speed of the Coolpix 990 varies from 1/1000 s to 8 s and since its aperture can take nine values between *f*/2.5 and *f*/7, the Exposure Value varies from -0.36 to 15.57 according to the Eqn.1. Each value of the EV scale thus corresponds to a great number of setting combinations.

The image produced by the Nikon is in color. This means that each pixel comes with a set of RGB components (Red, Green, Blue). In order to separate the color information from the luminance information, we decided to use the CIE Lab color space (CIE, 1986) instead of the default RGB color space. The CIE Lab has the advantage of being based on human physiology rather than on a technology like the RGB (for screens) or CMYK (for prints). The CIE Lab defines a color based on its lightness (L^*) and its chromaticity coordinates (a and b). The lightness value is expressed from 0 (black) to 100 (white). The a and b coordinates can be positive or negative. They vary from -128 to +128. A positive value of *a* is red, a negative value is green. A positive value of *b* is yellow, a negative value is purple. The advantage of using the CIE Lab is that the camera can be calibrated independently in luminance (using the L^* value of each pixel) and in chrominance (using the *a* and *b* values of each pixel).

Therefore, the change of color space is the very first step in processing the images of the Nikon Coolpix. Then, the luminance calibration consists in finding the relationship between the lightness of a pixel (L^*) and the luminance of the point it represents in the scene (L). As mentioned above this relationship depends on the *EV*.

III.2 The experimental setup

The idea behind the experimental setup was to produce as many lightness/luminance couples as possible for a given *EV*. We chose to use the luminous ceiling of our artificial sky as a quasi-uniform light source, which could be dimmed gradually. We placed under the ceiling a grid of 9 squares fitted with different widths of a translucent material (see Figure 2).

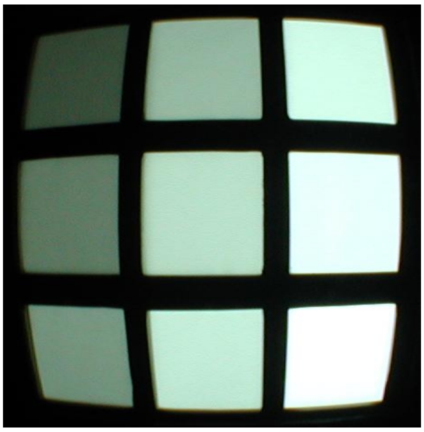

Figure 2: Picture of the 9 square grid produced by the camera.

By combining the dimmable luminous ceiling with the 9 squares of different transmission coefficients, we were able to obtain luminances ranging from 2 cd/m^2 to 4000 cd/m^2. We used a calibrated Minolta luminance meter LS100 to measure the luminance (L) at the center of each square. The image produced by the camera was processed through Photoshop to obtain the corresponding lightness (L^*) of each square.

Of course, this experimental device wasn't able to calibrate the Coolpix 990 in the range of the high luminances. It was in fact not possible to produce enough lightness/luminance couples for the upper part of the *EV* scale.

In order to have access to luminances higher than 4 kcd/m_ we used a sky scanner EKO MS-300. The constructor promises an accuracy of about 15 cd/m_ on measures up to 55 kcd/m_. The sky scanner (Figure 3), for each measures cycle, records the luminance in 145 equidistant directions of the hemispheric sky vault, in an interval of 3 minutes and 30 seconds. The points of measurement are following the model developed by Tregenza (1987): each of them represents a comparison point for the calibration of the Coolpix.

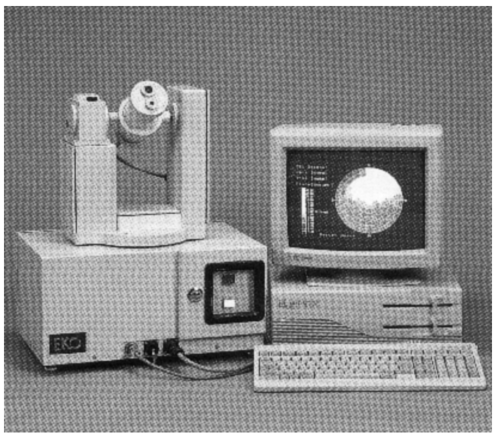

Figure 3 : Sky scanner EKO MS-300.

In order to be sure to produce standard values with the sky scanner, we compared its measures to the data provided by our IDMP station (especially the diffuse horizontal illuminance). The analyze of the results allowed to calculate a correction factor we applied to the luminances recorded by the EKO MS-300. This outdoor calibration completed the one performed under the artificial sky.

III.3 The results

For the calibration we need to cover the part of the *EV* scale really used by the Coolpix 990. We chose to determinate the relationship between a pixel lightness (L^*) and its corresponding luminance (L) for the Exposure Values distributed between 3.26 and 15.57 *EV*. Figure 4 presents a few results obtained with the artificial sky: for a given *EV* all points are located on the same curve. These curves have been completed with the data produced by the sky scanner: the Figure 5 shows an example of final calibration curve (for 14.57 *EV*). For each *EV*, the best fit was obtained with a relationship of the type:

$$L = \mathbf{A}(EV)\ \exp\ [\ \mathbf{B}(EV)\ L^*] \quad \text{(Eqn. 2)}$$

The luminance is an exponential function of the lightness of the pixel. The coefficients **A** and **B** of this function depend on the *EV*. In other words, like the human eye, the CCD response is a logarithmic function of the luminance.

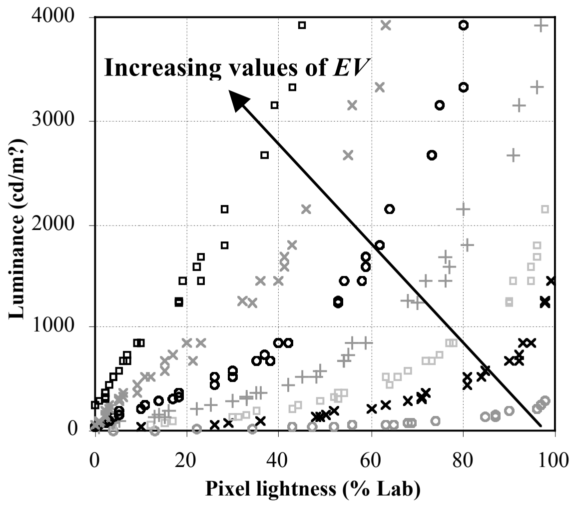

Figure 4: Relationship between L and L^* for different values of *EV* (6.55, 8.49, 10.52, 11.54, 12.57, 13.54 and 14.57 *EV*).

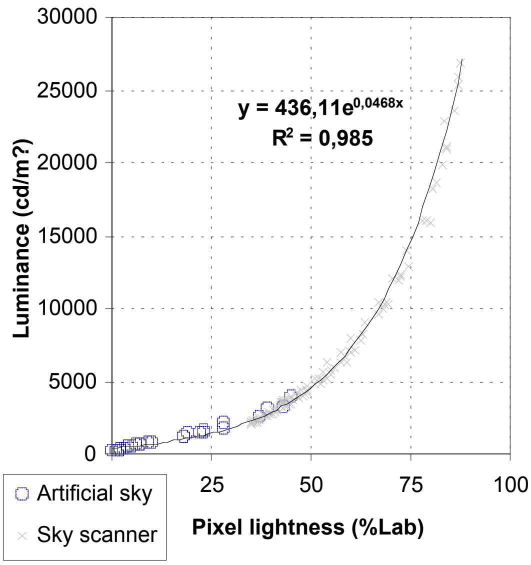

Figure 5: Relationship between L and L^* for 14.57 *EV*.

We looked at the variations of the **A** and **B** coefficients with *EV*. Figure 6 below shows their respective expression.

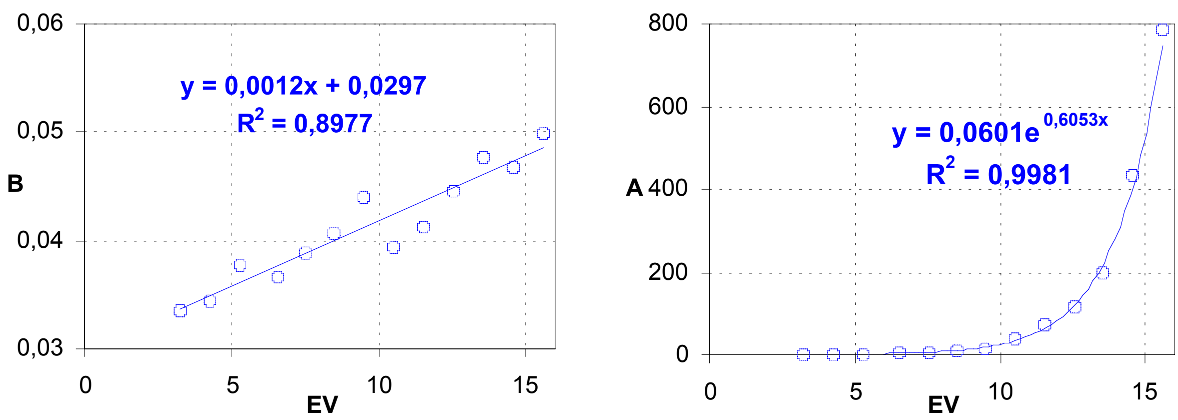

Figure 6: Variations with *EV* of the **B** coefficient (left) and the **A** coefficient (right).

We thus conclude that the luminance can be computed from the lightness of the pixel using the following expression:

$$L = 0.0601 \exp[\, 0.6053\, EV + (\, 0.012\, EV + 0.0297\,)\, L^* \,] \quad \text{(Eqn. 3)}$$

IV. APPLICATION OF THE RESULTS AND CONCLUSION

We used the results of this study to develop a computer program to automate the processing of the images coming from the Nikon Coolpix 990. This program called PhotoLux reads the information contained in the header of the image and checks the different settings of the digital camera. Then, it computes the luminance of each pixel with Eqn. 3 and produces a luminance map: a false color GIF image where each pixel is colored according to its luminance level. Figure 7 shows an example of luminance distribution in an office.

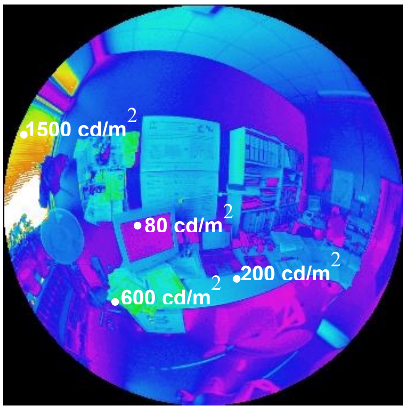

Figure 7: The luminance map of an office produced by PhotoLux.

Typically, the luminance map would be used to evaluate the visual comfort conditions in the office: by comparing the luminance of the screen and the desk's one you can conclude that the situation is uncomfortable. However, the analysis would not be complete without an evaluation of the glare condition. Photolux allows this analysis: the UGR (Unified Glare Rating) can be computed according to the formula provided by the CIE (1995). If the analyzed picture shows saturated zones (as the window on the Figure 7), the software is configured to take into account an additional image, this one being underexposed. The pixels saturated in the first picture are replaced by the same pixels non-saturated from the second picture.

The new generation of digital cameras offers great perspective in the production of luminance maps. We have shown that the Nikon Coolpix 990 could be used for that purpose and would allow evaluation of the glare condition. We think now to expand Photolux to the computation of other glare indices (DGI, VCP, GGR…) in order to test the validity of the UGR system.

V. REFERENCES

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