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# Digital Image Facilities for Visual Comfort Evaluation

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# DIGITAL IMAGE FACILITIES FOR VISUAL COMFORT EVALUATION

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## SUMMARY

Visual comfort depends not only on visibility and on the retina illuminance level but also on the luminance distribution in the visual field and on the colorimetric values of the detected surfaces. In this context, recent progress made in numerical image technology offers interesting opportunities in the field of photometric measurement. Digital cameras can in fact be used as flexible and powerful luminance meters. Considerable calibration and image treatment work is necessary for this purpose, but associated with an appropriate algorithm, they permit evaluation of the visual ergonomics of a work place (in particular with a video display terminal)

**Key Words**: digital camera, visual comfort, visual colorimetry, light, daylight

## 1 INTRODUCTION

Specialists in ergonomics aim to advise people on how to arrange their work place in order to best accomplish their tasks. The multiple video display terminals (VDT) that dominate offices nowadays make it necessary to pay special attention to the luminous environment. In order to evaluate and improve the visual ergonomic field, the specialist therefore first needs to describe the luminous condition.

Recent work in ergonomics [1] [2] proposes new models to evaluate visual performance and visual comfort at a work place. These novel indexes require among others knowledge of the luminance (photometric and colorimetric) repartition in the view field.

In this context, a new photo-colorimetric luminance meter based on the digital imaging technology has been developed. Similar devices, based on a single gray level CCD camera with three colorimetric filters, exist already. But, they are very expensive and cannot supply 180° view field images. This is why we have decided to propose one with a common CCD color (RGB) camera for the general public and to develop calibration protocols and image treatment methods to obtain information with an acceptable accuracy.

## 2 OPERATION PRINCIPLE

Devices based on the numerical image technology consist of the following elements:

a) detector: to convert light into an electric signal
b) filters: to fit the spectral response of the detector to the photo-colorimetric curves
c) optics: allow to project the measured scene on the detector
d) electronic amplification of the detector signal
e) electronic digitalization of the signal
f) image command, acquisition and processing software: belongs, with a Personal Computer, to the control unit

## 2.1 Camera

There are numerous technical criterions to take into consideration for the choice of a camera. **Table 1** gives the main characteristics to be considered. All cameras are composed of elements a) and d) (cited above). Digital cameras also directly integrate the element e) in the body of the device.

| **Parameters** | **Comment** |
|---|---|
| Sensor type | Principally using the CCD (Charge-Coupled Device) technology, the sensor can be in black and white (gray level) or color (single or 3 CCD RGB, CMY) |
| Signal/noise factor | This factor should be maximized to improve the quality of the final measurement.<br>For a low light level it is important to have a cooled CCD (by Peltier effect) |
| Adjustment | All adjustment parameters of the camera (like Gamma curve, gain, integration time, color balanced, etc…) have to be controlled or, at least, to be fixed. |
| Resolution | Combined with the type of the optics, the resolution of the sensor determines the spatial resolution of the device |
| Camera body | Size, weight, optical mount, autonomy level of the system are important parameters for the final use |

**Table 1:** summary of the main parameters of the camera

## 2.2 Filters

The filters constitute a particular element of a photo-colorimetric calibrated camera. They allow fitting the sensor spectral sensitivity to the CIE 1931 2-deg XYZ color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ (see Figure 2). It is essential to obtain a correct measurement according to the CIE definitions [3].

Generally CCD cameras possess a built-in infrared filter. Gray level CCD requires a yellow-green filter to correspond to the standard universal observer defined by the $V(\lambda)$ curve (equal to the $\bar{y}(\lambda)$ color matching function).

Different versions of color CCD cameras are available:

- 3 CCD with a dichroic filter prism: more expensive, this kind of camera has difficulty in mechanically aligning the three images.
- single Red Green Blue CCD: directly set down on the CCD the 3 filtered kinds of pixel constitute a mosaic. Most common, this technology is kept for the photo-colorimetric measurement application presented in this paper.
- single Cyan Magenta Yellow CCD: similar to the RGB, these 3 filters give a better light sensitivity to the detriment of the color accuracy. This is why this technology is not retained.

# 3 Calibration Procedure

The calibration procedures are fundamental to correct measurement. Two main calibration procedures are distinguished:

- Photo-colorimetric: the exact spectral sensitivity of the camera response has to be known. After which, RGB colour images are treated to correspond to the standard CIE XYZ format [3]. Afterwards, the spectral calibration is controlled, the relationship between digital level and photometric value (in $cd/m^2$) is determined
- Spatial: each lens installed on the camera gives a different correspondence between image pixel position and the direction of the photographed object. Thus, this geometrical relation has to be found.

### 3.1 Photo-colorimetric calibration

The experimental facilities for the photo-colorimetric calibration (see Figure 1) consist in a monochromatic source (tungsten halogen lamp with a monochromator) that delivers a uniform light spot on a neutral standard white target. This monochromatic (± 10nm wide) light spot is measured on one side with the spectrophotometer and photographed on the other side with the camera (not visible on the Figure 1).

One photograph of the target is taken at the same time as a measurement with the spectrophotometer is carried out. The camera image is background corrected and linearized. Related to the target radiance, the digitalized level (3x8bit) gives the relative spectral response of the three colored filters on the CCD camera. This result is given in Figure 2.

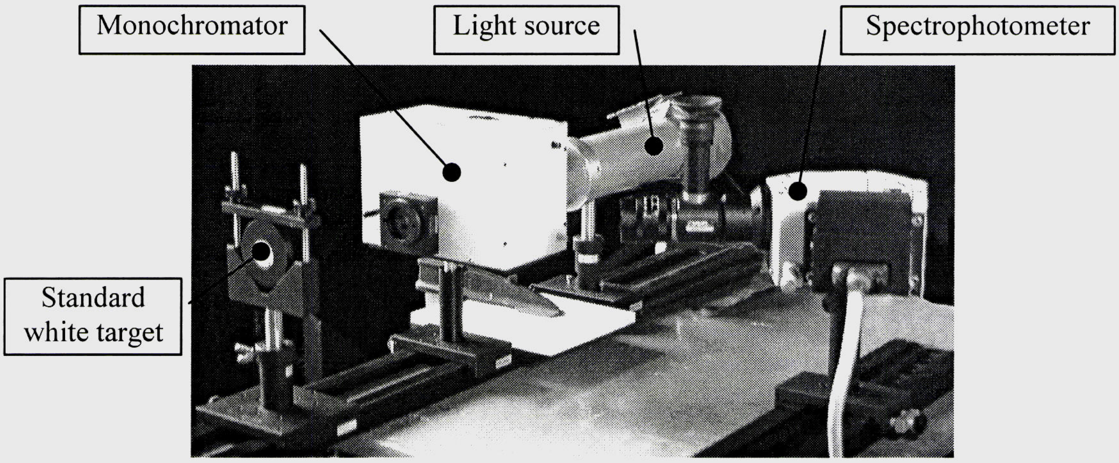


Figure 1: experimental facilities for the photo-colorimetric calibration

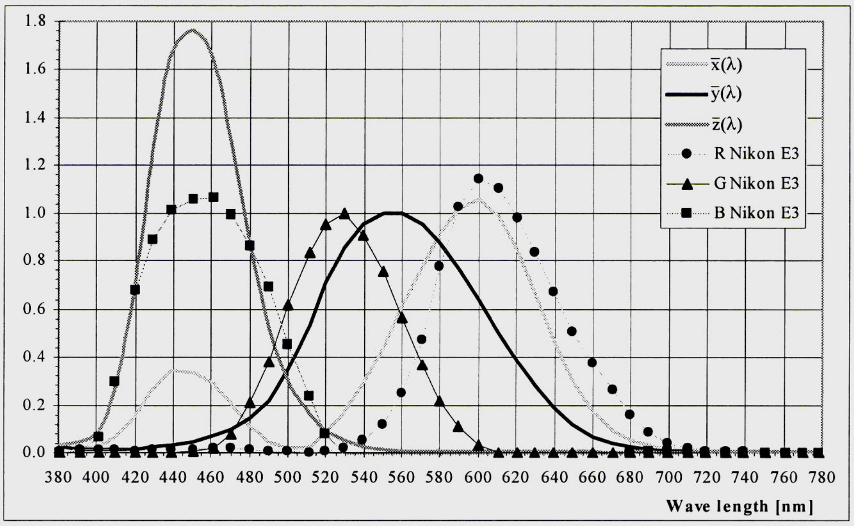


Figure 2: Measurement result of color matching function $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ and relative spectral response of the RGB color CCD camera (Nikon E3)

The next step of the calibration procedure consists in finding the best fit for a linear combination of the RGB values. A Newton type method is used and gives the results presented in Figure 3. They represent the following linear combination:

$$\begin{aligned}
\bar{x}_{\text{Nikon E3}}(\lambda) &= \left|(-4.072 \cdot R(\lambda)) + (-0.481 \cdot G(\lambda)) + (0.354 \cdot B(\lambda))\right| \\
&\quad + \left|(0.874 \cdot R(\lambda)) + (0.332 \cdot G(\lambda)) + (-2.956 \cdot B(\lambda))\right| \\
\bar{y}_{\text{Nikon E3}}(\lambda) &= \left|(0.510 \cdot R(\lambda)) + (1.034 \cdot G(\lambda)) + (-0.879 \cdot B(\lambda))\right| \\
\bar{z}_{\text{Nikon E3}}(\lambda) &= \left|(-15.502 \cdot R(\lambda)) + (-0.923 \cdot G(\lambda)) + (1.711 \cdot B(\lambda))\right|
\end{aligned} \qquad (1)$$

To get a better fit, the $\bar{x}(\lambda)$ color matching function is separated into two parts: one for wavelengths smaller and the other for wavelength bigger than 505 nm. Absolute values are taken to stay in the physically possible domain. The results are given as examples and correspond to a particular camera adjustment. By calculation, an evaluation of five different colored targets (reflectance calibration standards) is carried out. These results are presented in Figure 4.

After the colorimetric calibration has been accomplished, the absolute photometric calibration can be carried out. In other words, each digital level of the Y-image has to correspond to a luminance value in cd/m$^2$. Depending on the camera settings, the luminous full scale corresponds to a dynamic range of ~10dB. To obtain a bigger range, several images in different settings (aperture, exposure time) have to be combined. In the reference [4] a video sky scanner is described. This device can measure all luminance values (sky and sun) of a clear sky, which corresponds to a ~75dB dynamic range, with a precision less than 1%.

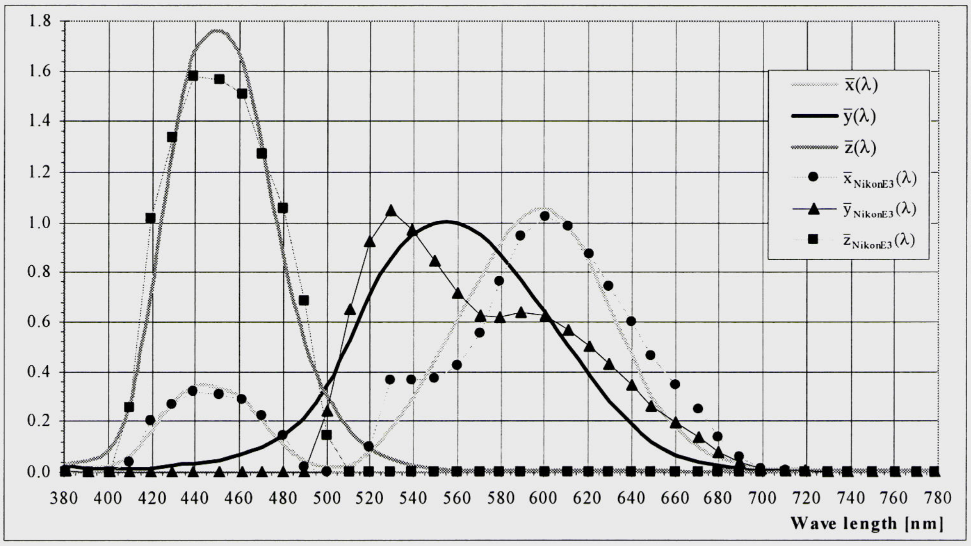


Figure 3: Fitted color matching function of the RGB color CCD camera (Nikon E3) compared with the CIE 1931 color matching function. The linear combination is given in the equation (1)

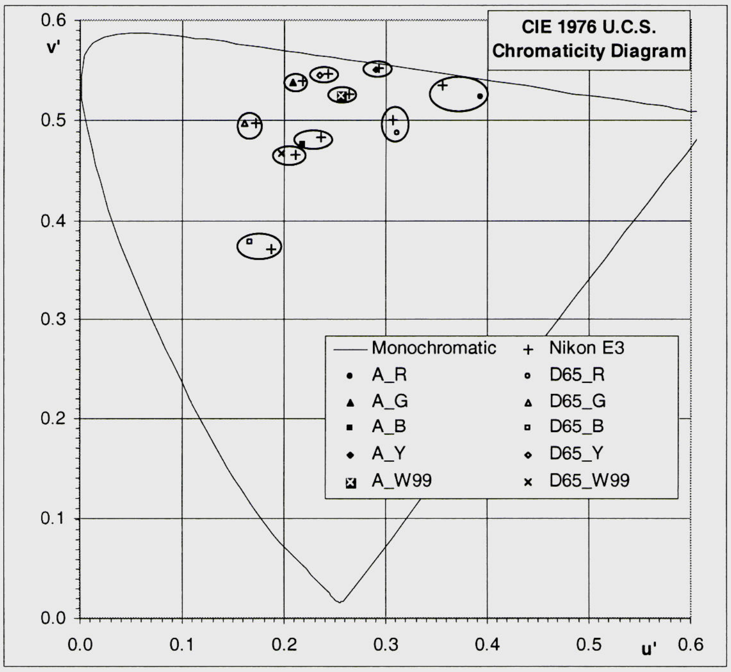


Figure 4: Evaluation by calculation, of different color reflectance calibration standards. Small ellipses group the theoretical and camera measured points corresponding to one colored target.

## 3.2 Spatial calibration

Whereas a broad field of lenses from wide-angle to telephoto exist, fish-eye lenses with a view angle of 180° are not easy to find for CCD, because of the small size of existing sensors. The trend is not to conceive lenses with a very short focal length, but to increase CCD dimensions.

The digital camera used for this preliminary study (Nikon E3) has a built-in reduction optical system to reduce 24x36mm conventional images to fit a 2/3" CCD sensor (see Figure 5). This principle, today abandoned by Nikon, has the disadvantage to decrease the image quality and the optical aperture.

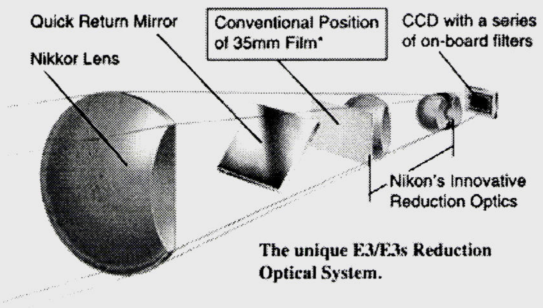


Figure 5: The Nikon Reduction Optical System (ROS) achieves practically identical picture angles when the same Nikkor lens mounted on either an E Series digital or a Nikon 35mm [135]-format SLR camera (Source: Nikon Corporation)

is

An empirical relation is found to link the spatial position of a point with its position on the image. The relation is given in equation (2); position and angles are described in Figure 6.

$$\begin{cases} x = 628 - d \cdot \sin(\theta) \\ y = 492 - d \cdot \cos(\theta) \end{cases} \qquad (2)$$

with (see also Figure 6):

x: horizontal position of the pixel of a considered point P

y: vertical position of the pixel of a considered point P

$\varphi$: azimuth angle of a considered point P

$\theta$: elevation angle of a considered point P

d $= 0.0054 \cdot \varphi^2 - 5.78 \cdot \varphi$ ($\varphi$ is in degree)

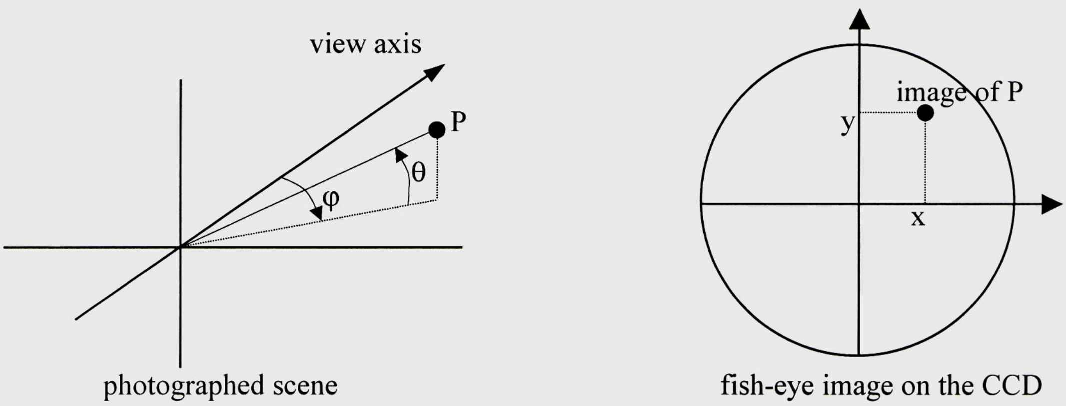


Figure 6: description of the position angle of a point P in the photographed scene and the corresponding pixel position in the image.

## 4 Experimental Implementation

At the time of the printing deadline for this article, the calibration work is not precise enough to present ergonomic evaluation results. Nevertheless, digital fish-eye image coupled with traditional luminance measurements give in Figure 7 a good idea of the expected results of the experimental implementation of this device.

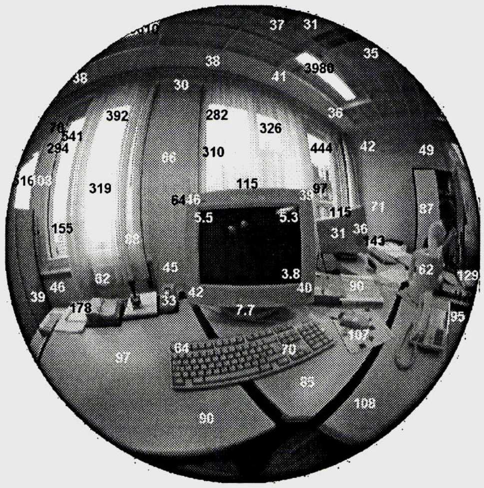


Figure 7: illustrative example: fish-eye photograph of work place in an office. The superimposed numbers are measured luminance values in cd/m$^2$.

## 5 Conclusion

One knows that a CCD RGB color camera cannot measure the photo-colorimetric values of a scene with a great precision. However, in the visual ergonomics field that is taken into account here, it would be absurd to look for great accurateness, as the luminous ambiance perception varies from one person to the other in any case.

Although, for the moment, the targeted camera calibration has not yet been achieved, one can expect that such a device will offer the specialist in visual ergonomics an efficient and useful field tool. It should allow evaluating work places with quick efficiency.

## Acknowledgements

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## References

1. Francioli, D., J.-J. Meyer, and H. Kerkhoven. *New light measuring methods for the determination of the discomfort index "J" and the set-up of a data bank.* in *Lux Europa 1997: the 8th European Lighting Conference*. 1997. Amsterdam.

2. Francioli, D., J.-J. Meyer, and L. Michel. *New global indexes for visual comfort.* in *International Lighting Congress*. 2001. Istanbul.

3. CIE15, *Colorimetry, 2nd Edition*. 1986, Commission Internationale de l'Eclairage (CIE): Vienne.

4. Michel, L., *Méthode expérimentale d'évaluation des performances lumineuses de bâtiments*, in *Département d'Architecture*. 1999, Ecole Polytechnique Fédérale de Lausanne (EPFL): Lausanne. p. 209.