P-17 : Uniformity calibration of large area full color light emitted diodes screens

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Abstract

In this paper, we describe a powerful solution for efficient LED wall calibration through the use of a quality 2D-luminance meter : the MURATest and a dedicated applicative software.
The intended calibration allows adjusting individually the intensity of each LED so as to obtain a good uniformity on the module. Furthermore the intensity of each module can be adjusted one to the others so as to obtain a good uniformity on a complete display and maintain it even after module exchange for display maintenance needs.

1. Introduction

Light Emitting Diodes (LED) are now widely used in large area screens. Since the availability of high efficient blue LEDs, full color large area LED displays become possible. Their high luminescence, high efficiency and long life span combined with high sharpness, color rendering and low cost maintenance make them particularly attractive for outdoor use. On the other hand users become more and more sensitive to display's defects.

The most important to deal with is currently the uniformity defect. LED displays particularly suffer from uniformity because of the dispersion on LED characteristics. Since it is very difficult to assemble only LEDs with similar luminance in a panel, a compensation circuitry is usually used. A calibration step is then needed to provide one coefficient per LED that is used to adjust the electrical signal so as to compensate for LED variations.

2. Experimental details

The LED module on which is displayed a uniform pattern is imaged with a 2D luminance meter called MURATest. Its optic is telecentric so as to avoid any viewing angle effect. In fact, with conventional optic, light collection decreases with a cos4θ factor (the apparent surface of the LED decreases when the LED is in the corner of the module, and the distance to the optical aperture becomes bigger). This effect is automatically corrected with the MURATest. A low noise and high resolution (1024x1536) cooled CCD is included in the system. It has no anti-blooming so as to ensure a maximum filling ratio (100%) and no signal leakage. The high resolution allows measuring large area screens with a great number of LEDs in only one acquisition. Cartography of luminance (candela/m²) is obtained directly on the module.

To check the accuracy of our experiment and analysis software, we use four different patterns composed of aligned transparent holes on a black background such as presented in Figure 1. The patterns are generated with the micro electronic technology so as to benefit from a very accurate surface for each hole.
The characteristics of the patterns are summarized in Table 1. Patterns 1, 2 and 3 have three class of holes randomly distributed in the pattern. Pattern 4 has only one class of holes. Each pattern is placed in a dark room, in front of an integrating sphere used as uniform source. A luminance image is then acquired with the Muratest.

Since the integrating sphere spatial uniformity is not perfect, a reference image of white is also acquired. One normalized result is reported in figure 1 in the case of pattern 1.

	Pattern 1	Pattern 2	Pattern 3	Pattern 4
Class 1	ϕ=2 mm 480 holes	ϕ=2.25 mm 480 holes	ϕ=2 mm 672 holes	ϕ=2.5 mm 3360 holes
Class 2	ϕ=2.25 mm 480 holes	ϕ=2.375 mm 480 holes	ϕ=2.25 mm 672 holes	-
Class 3	ϕ=2.5 mm 480 holes	ϕ=2.5 mm 480 holes	ϕ=2.5 mm 672 holes	-
Class 4	ϕ=2.75 mm 480 holes	ϕ=2.625 mm 480 holes	ϕ=2.75 mm 672 holes	-
Class 5	ϕ=3 mm 480 holes	ϕ=2.75 mm 480 holes	ϕ=3 mm 672 holes	-
Distance between holes	6.5 mm	6.5 mm	5.5 mm	5.5 mm
Filling ratio	31 to 50%	35 to 46%	36 to 54%	45.4%

n

Table 1: description of the patterns used for the

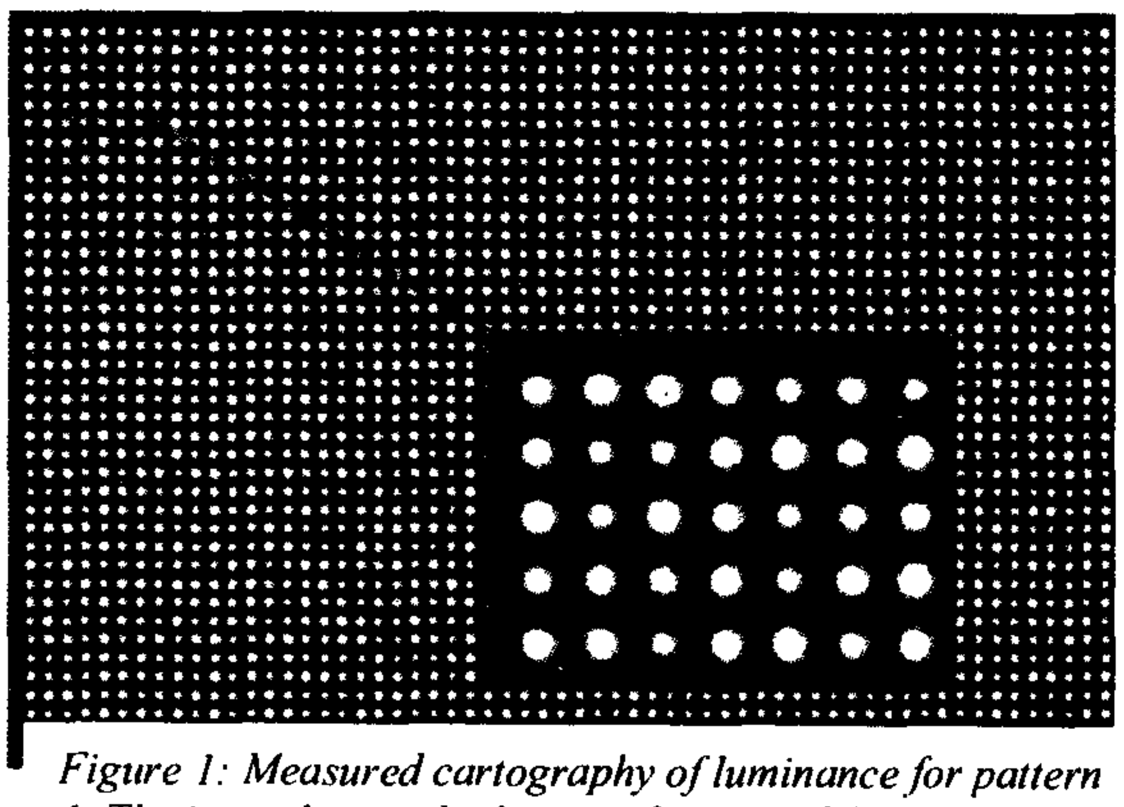

Figure 1: Measured cartography of luminance for pattern 1. The inset shows a high magnification of the top left part of the pattern.

3. Software description and performances

The software used to quantify light intensity for each LED goes through the following steps:

-Calculation of the optimized threshold to detect each blob.

-Detection of a unique maximum per blob and suppression of any false maximum.

-Ordering of the blobs in an array even if the image is tilted and blobs not perfectly horizontally aligned.

-Integration of the intensity on each blob.

-Normalization of the intensity in Candela with the knowledge of the CCD pixel relative size.

The software is able to handle square matrix like the one in figure 1, but also interlaced structure where one line over 2 is shifted of half a horizontal period.

3.1. Definition

To optimize the analysis procedure, the different test patterns of table I have been measured. In each case, we calculate the intensity of all the blobs in the image (cf. figure 2). From this result we can plot the distribution of intensities that can be split in different contributions coming from the different class of blobs (5 classes in the case of figure 1 and 2 has shown in figure 3).

An average intensity $\overline{I_{ClassIndex}}$ and a standard deviation $\sigma_{ClassIndex}$ are evaluated for each class. (cf fig 5).

The term "dispersion" design the ratio (in %) of the standard deviation compared to the average intensity. It is a good indication of the accuracy of the method.

$$D^{****}_{++++} = \frac{\sigma^{****}_{++++}}{\overline{I_{++++}}} * 100$$

Then repeatability assessment needs to compare the results obtained from multiple images. First, the previous $\overline{I_{ClassIndex}}$ .can be compared within each class on the multiple images, what gives new average and standard deviation for each class.

$$\overline{I^R_{classIndex}} = \overline{(\overline{I_{classIndex}})}_{|\{images\}}$$

$$\sigma^R_{classIndex} = \left(\sum_{n=1}^{N}(\overline{I_{classIndex}} - \overline{I^R_{classIndex}})\Big/N\right)^{1/2}$$

Then, more precise statistics are obtained if evaluating an average and standard deviation for each blob : $\overline{I^R_{x,y}}, \sigma^R_{x,y}$.
Representative figures are given by average and maximum dispersion evaluated on every (x,y)

$$D^{RMax} = MAX_{\{x,y\}}(\sigma^R_{x,y}\Big/\overline{I^R_{x,y}})$$

$$D^{RAverage} = \overline{\sigma^R_{x,y}\Big/\overline{I^R_{x,y}}}_{|\{x,y\}}$$

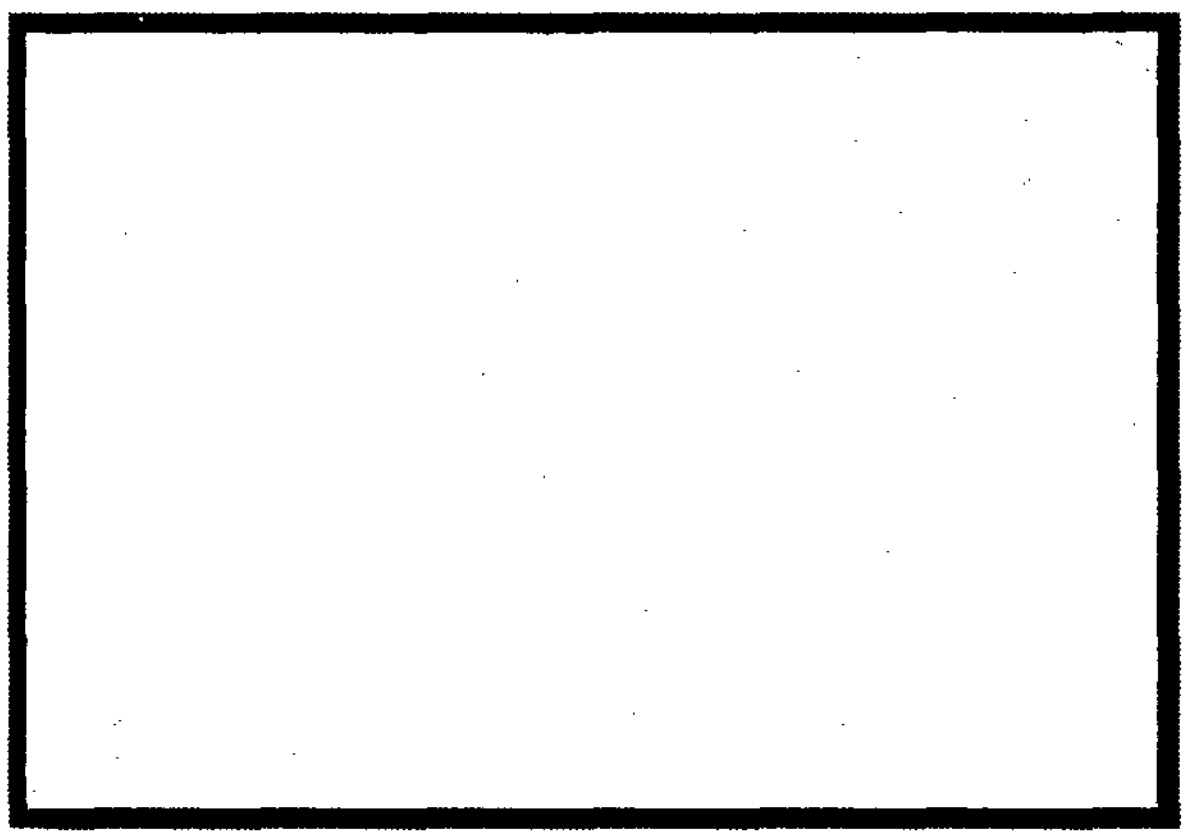

Figure 2: Extracted LED intensities from the image of figure 1.

3.2. Calculation of the optimized threshold

Once identified a unique max per blob and sorted into an array, a sum of luminance is performed on a window around each maximum. Two approaches are available: summing only pixels above a given threshold (so as to avoid taking into account noise), or summing intensity on every pixel on the window (expecting that noise will be averaged). An evaluation of the accuracy of the first method has been made versus the threshold value on the data of figure 1. As shown in Figure 4, the thresholding algorithm that sum intensity on the neighboring window only for pixel above 1/30th of the maximum luminance is a good compromise (~550mCda/m2 compare to 171.6 cda/m^2 for the maximum luminance on this image).

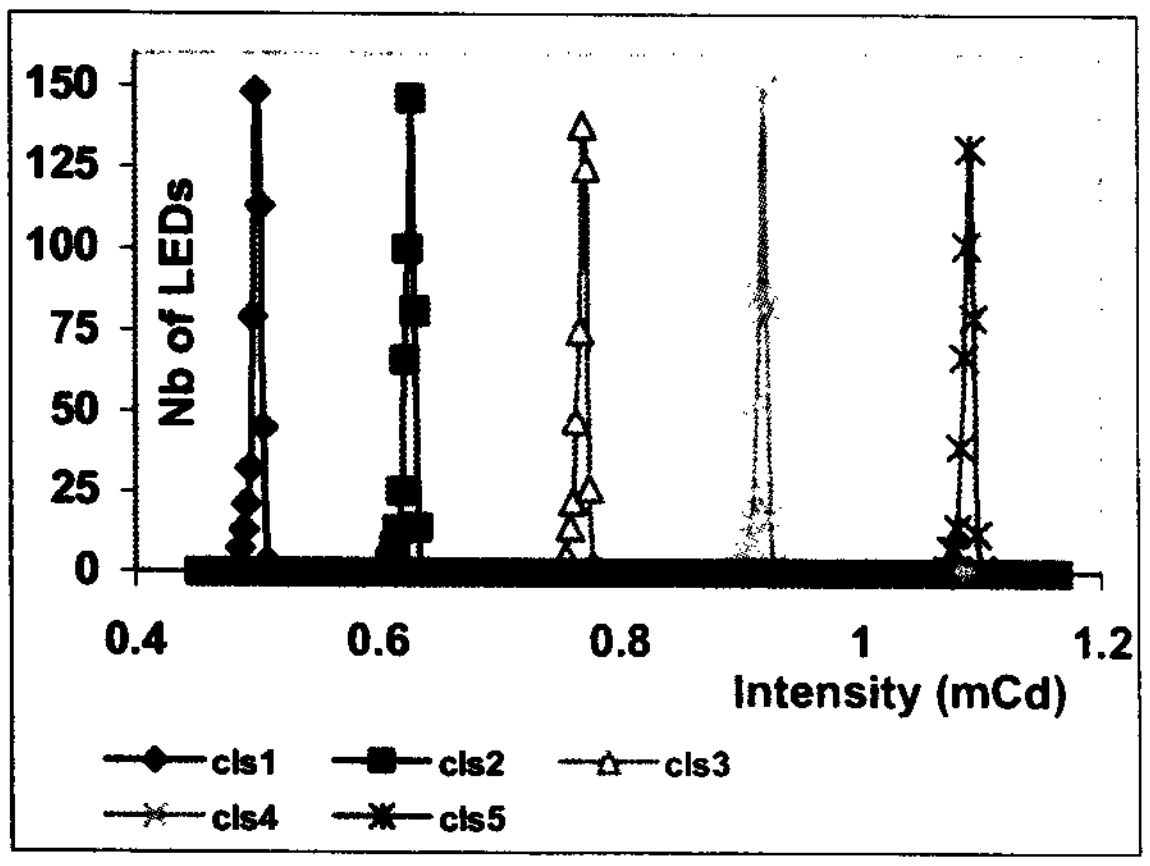

Figure 3: Histogram of the LED intensities for each class deduced from figure 2.

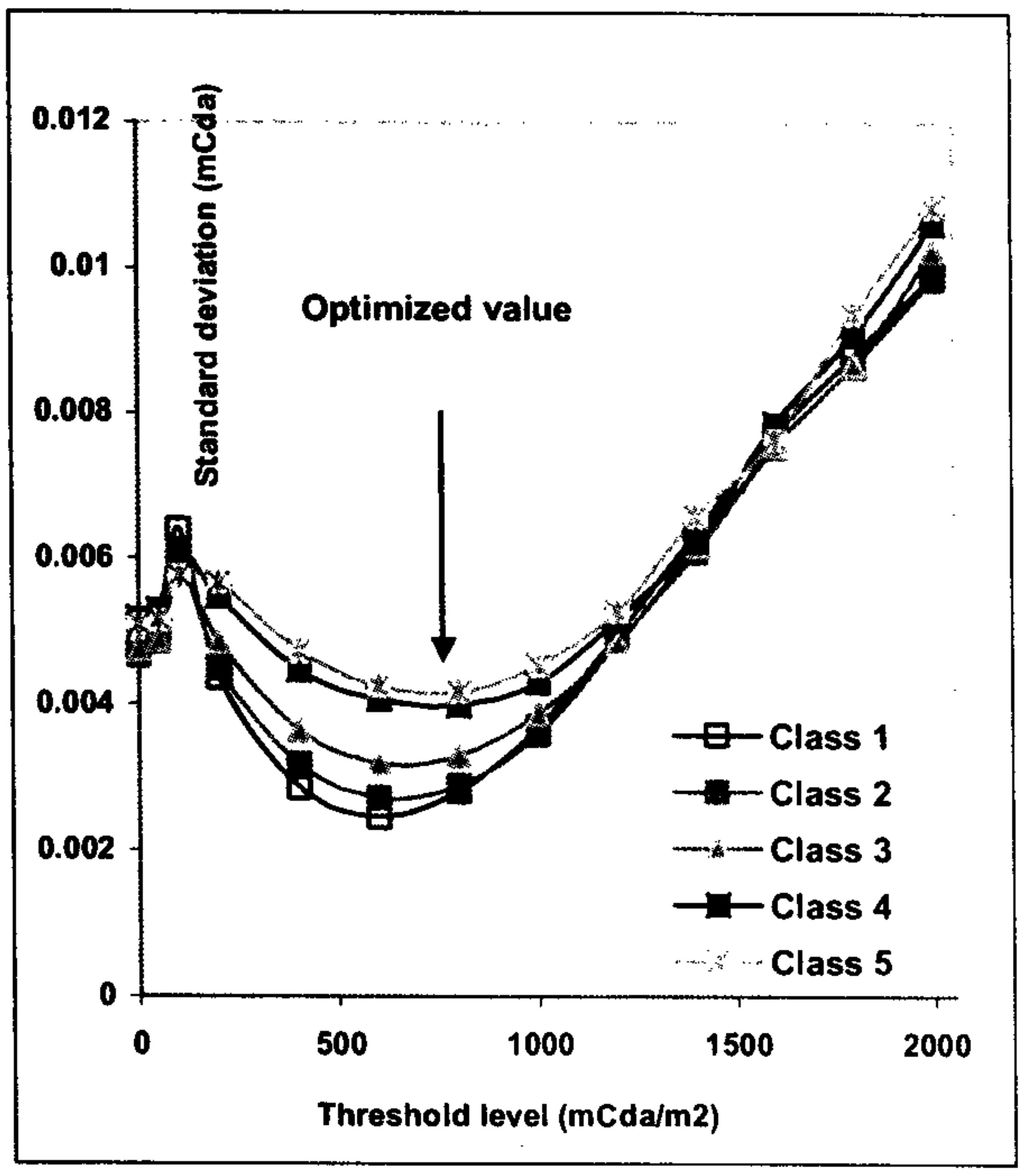

Figure 4: Standard deviation on integrated LED intensity versus threshold level.

3.3. Normalization of the results

Since we chose to use a thresholding method (so as not to suffer from noise), we miss a part of the signal below the chosen threshold. An absolute calibration is obtained using the ratio between average value on whole LED with threshold equal to 0 and with optimized threshold.

The nominal intensity for each LED can be theoretically predicted using:

$$I = Lum * S$$

Where Lum represent the luminance of the integrated sphere (cda/m^2) and S represent the surface of the hole (m^2). On Figure 5, the theoretical values are compared with the medium experimental one's for pattern 1. The agreement is very good for each size of hole.

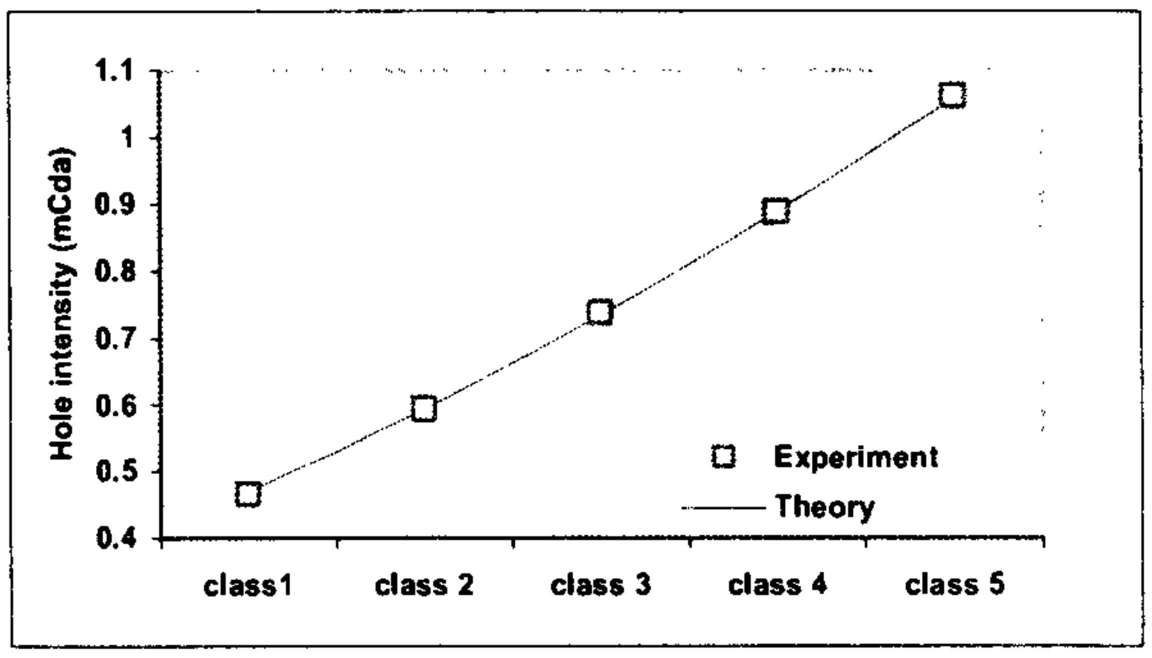

Figure 5: Intensity of the tree class of holes of pattern 1.

3.4. Accuracy and repeatability

A summary of the results obtained on the four different patterns is reported in Table II. For patterns 1, 2 and 4 the dispersion is inferior to 0.5 % for every class. It shows that the equipment and process are very accurate.

		Cls 1	Cls 2	Cls 3	Cls 4	Cls 5
pattern 1	σ_i	0.0025	0.0027	0.0034	0.0042	0.0045
	D_i (%)	0.49	0.41	0.41	0.42	0.37
pattern 2	σ_i	0.003	0.003	0.004	0.004	0.004
	D_i (%)	0.44	0.43	0.43	0.44	0.39
pattern 3	σ_i	0.006	0.006	0.007	0.007	0.008
	D_i (%)	1.12	0.87	0.81	0.75	0.67
pattern 4	σ_i	0.004				
	D_i (%)	0.52				

Table II: standard deviation and dispersion obtained for each class of hole.

In addition, for pattern 1, the repeatability of the method has been tested on 30 images acquired successively (with same scene and parameters) and analyzed. The standard deviation obtained on the average intensities evaluated for each class from all the images analysis equals 0.055%. The dispersion in intensity for each LED has also been evaluated. The average dispersion ($D^{RAverage}$) on every blob of the image is only 0.135% and the maximum dispersion (D^{RMax}) is about 0.6%.

	Cls 1	Cls 2	Cls 3	Cls 4	Cls 5
$\overline{I_i^R}$	0.5305	0.6768	0.8410	1.0131	1.2115
σ_i^R	0.000262	0.000372	0.000419	0.000526	0.000626
D_i^R	0.0493	0.0550	0.0498	0.0519	0.0517

Table III: Figure 1 : Average intensities, standard deviation and dispersion for each class evaluated from average intensities evaluated for each image.

D^{RMax} (%)	0.606493
$D^{RAverage}$ (%)	0.1346

Table IV: average dispersion and maximum dispersion evaluated from multiple images on the x y repartition of dispersions.

Here are the same results while performing shift and rotation on the pattern between acquisitions.

$\overline{I_i^R}$	0.5302	0.6763	0.8403	1.0122	1.2105
σ_i^R	0.000397	0.000493	0.000591	0.000716	0.000741
D_i^R	0.0748	0.0729	0.0703	0.0707	0.0612

D^{RMax} (%)	1.181907
$D^{RAverage}$ (%)	0.274215

Tables V: Statistics on quantification dispersion from multiple images taken with rotation and translation of the pattern between each acquisition.

Those previous figures prove our equipment and process to be very stable and accurate. One limitation of the technique is nevertheless related to the filling ratio of the surface. For low filling rate the intensity correctly going down to 0 between two blobs whereas high filling rate suffer from overlap. This overlap appear as an "offset" of the signal.

The dispersion coefficients are not of same quality for the 4 pattern described in fig 2. The dispersion for two first patterns are equal and very small (inferior to 0.5%) for every class of holes. The dispersion is twice worse for pattern 3 where only the distance between holes changes from pattern 1. This shows that the "filling rate" which means the proportion of holes diameter compared to black region, should not be too high. There is a direct correlation between this parameter and the dispersion of the results. For filling ratios about 31% the dispersion is less than 0.4% but can reach more than 1% when the filling ratio increases above 50%. This kind of limitation can be overcome by performing iteratively the calibration step with a progressive LED compensation.

Here is an example of results obtained from a real LED wall before and after compensation. The final dispersion is much smoother.

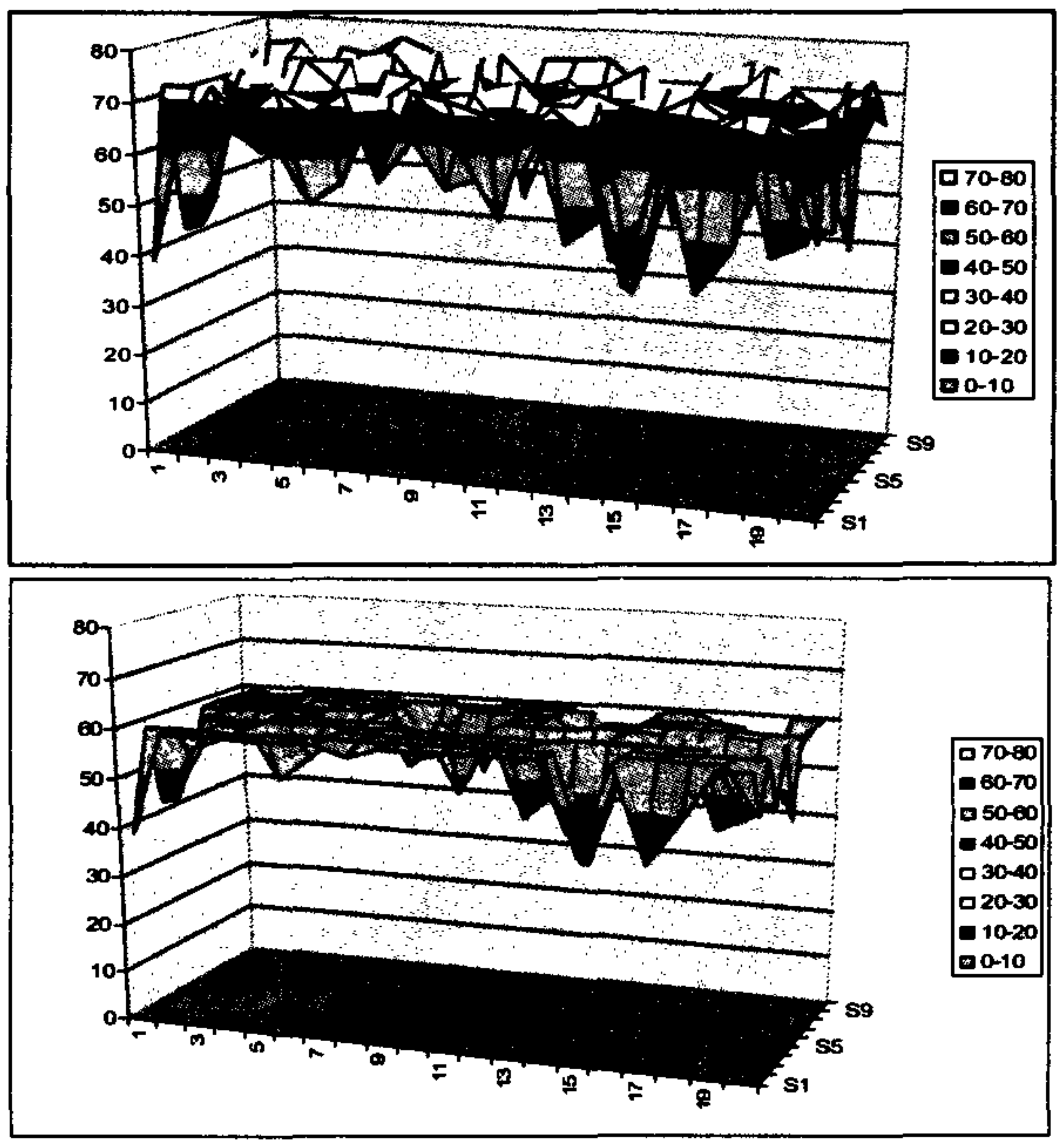

Figure 6 : LEDs dispersion before (a) and after (b) compensation.

4. Conclusion

We have described an experiment to calibrate the LED wall uniformity rapidly and very accurately. Using test patterns we have shown that the accuracy and repeatability of our tool is excellent when using filling rate beneath 40%. Above, an iterative calibration should be performed.

Our calibrating tools currently work for luminance calibration. A color calibration is possible (adding CIE color filters on the MURATest) through the combination of three similar analyses for red, green and blue pattern imaged through respectively red, green and blue CIE color filters. A single compensation is then sufficient to calibrate in color a LED Wall with separated color "pixel" (composed of 3 or 5 combined color LED). An iterative calibration will be needed for interlaced colored pixels.