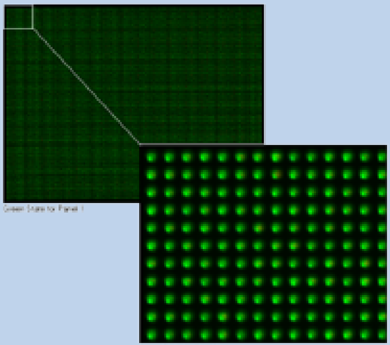
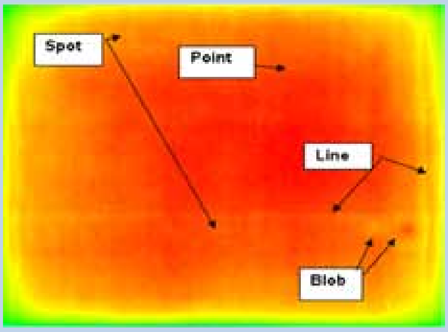
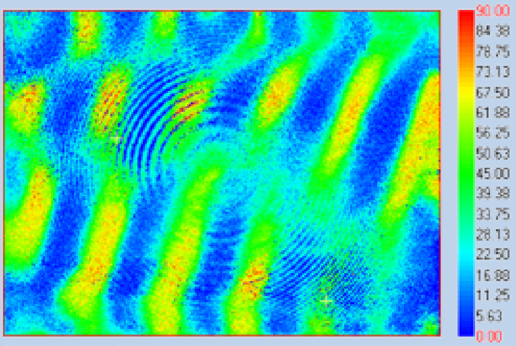
IMAGING DEVICES NEXT GENERATION







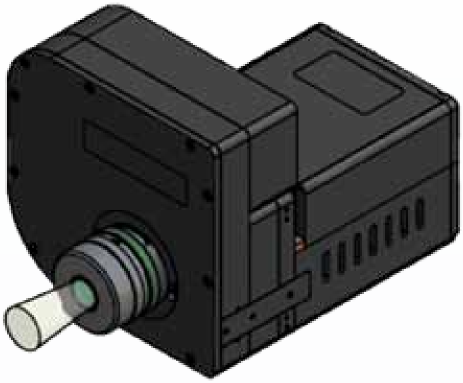
Polarization orientation

THE MOST ACCURATE HOMOGENEITY MEASUREMENT OF LUMINANCE, CHROMATICITY AND POLARIZATION

UMaster & UMaster-PZ

ADVANCED LIGHT ANALYSIS by **ELDIM**

Photograph of UMaster



Technical plans of UMaster Color & density wheels

Electron beam evaporator with ion beam assistance

UMaster description

Imaging colorimeters are all based on CCD sensors and generally color filters. The difference between the systems lays in the accuracy, the signal over noise ratio, the spatial resolution and the quality of the imaging optics. **UMaster** is based on a Peltier cooled CCD sensor with true 16-bit analog digital converter. Four color filters dedicated to each CCD sensor are mounted on a motorized color wheel. A second motorized wheel with flat densities is also available for an automatic adjustment to the source luminance.

High Accuracy

ELDIM is manufacturing on its own all the key components of its systems.The quality of the optics is optimum thanks to advanced technologies such as magneto-rheological polishing or stitching interferometry. Antireflective coatings and optical alignments are also performed in house to reduce straight light and parasitic polarization. **UMaster** uses an objective telecentric on the sensor side for imaging.The color accuracy is ensured using 4 dedicated color filters adapted to the spectral response of each CDD. **UMaster** uses a new technology based on electron beam evaporation that gives filters with higher transmittance and enhanced accuracy.

High Sensitivity

Peltier cooled CCD sensor with true 16-bit analog digital converter and color filters with high transmittance allow optimum sensitivity for **UMaster**. Large size CCD versions can be used to detect very low light levels while maintaining a good spatial resolution.

High Dynamic

UMaster integrates different neutral density filters on an automated wheel. These neutral densities are spectrally flat thanks to the use of interference coatings deposited on neutral glass. Automated control of these densities is available for each color filter independently to improve the accuracy in particular for LED type sources.

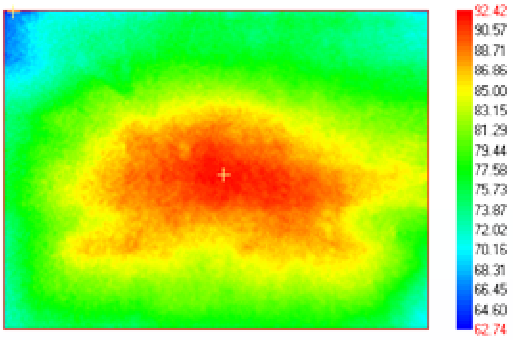
A range of imaging objectives

UMaster is available with objectives of different aperture (8° and 16°) and different CCD sensor resolutions (1M to 16M pixels). Additional optics for high spatial resolution are also available.

More than just Luminance & Color: Polarization

In addition to luminance and color imaging, **UMaster** can realize polarization imaging at different wavelengths. This option is available for all the wavelengths in the visible range (band pass 10nm). The system performs automatically seven measurements with different polarizers and wave plates from which it computes all the polarization parameters throughout the image in addition to radiance. Stokes vectors are available for each pixel of the image.

Data analysis and Software



Luminance of LCD display

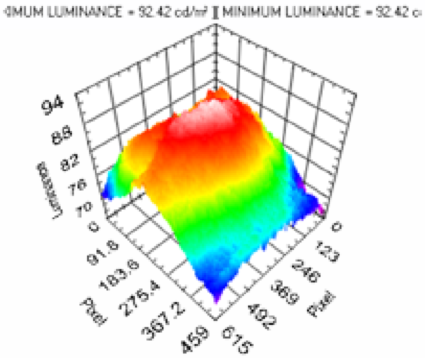
Each **UMaster** system comes with a powerful, Windows-based software suite created by **ELDIM**. This software provides extensive instrument control, data acquisition and image analysis capabilities. The software provides also a simple, user-friendly interface to fully automate pre-programmed capabilities. This enables each customer to perform sophisticated measurements and tests in a completely automated way with limited efforts.

Display Homogeneity

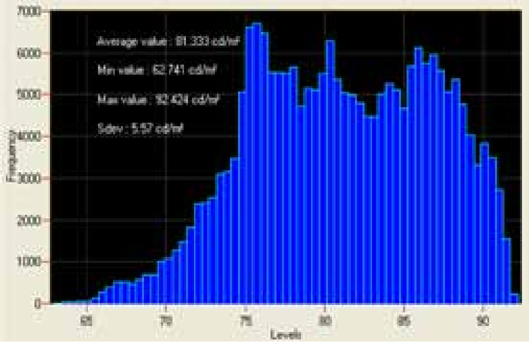
UMaster provides a number of tools to analyze easily the measurements including contour extraction and Moiré removal. The captured images can be immediately analyzed with comprehensive, integrated graphs, charts and spreadsheets for:

- Luminance
- Illuminance
- Luminous Intensity
- Total Luminous Flux
- Radiance
- Irradiance
- Radiant Intensity
- Total Radiant Flux
- CIE Chromaticity Coordinates (x,y and u',v')
- Correlated Color Temperature (CCT)
- Contrast ratio
- Ellipticity and polarization orientation
- Degree of polarization
- Stokes vector

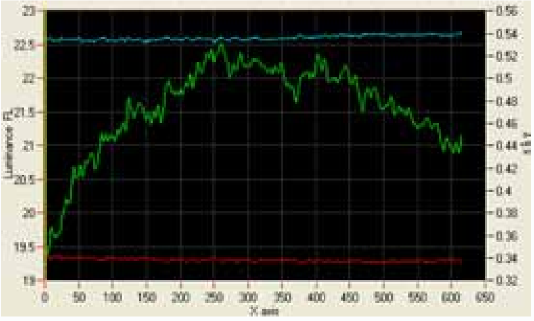
Data and graphs can be easily exported to other Windows applications.



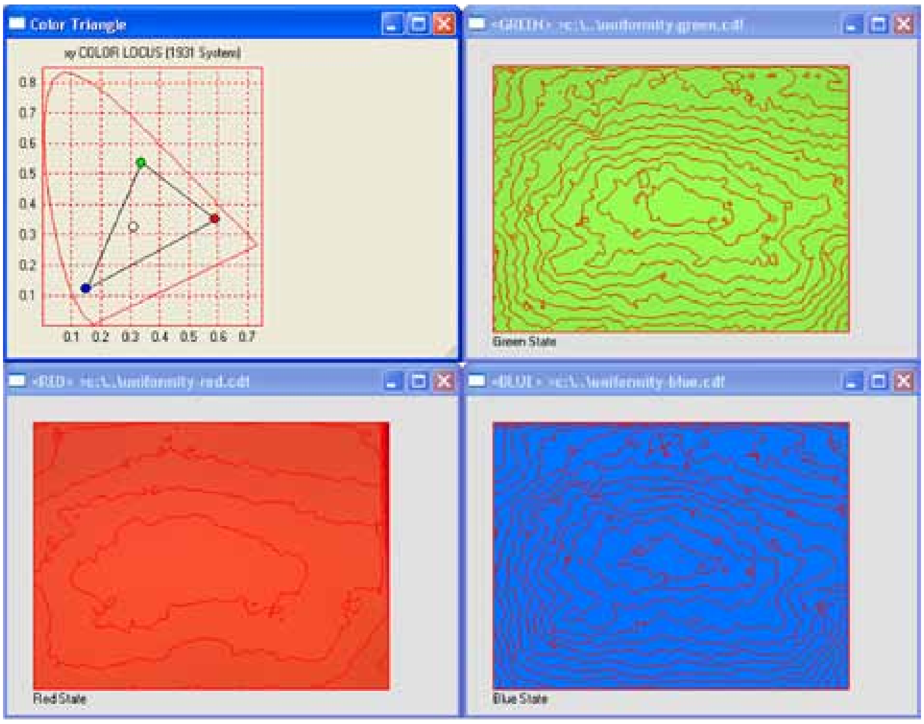
Luminance of LCD display



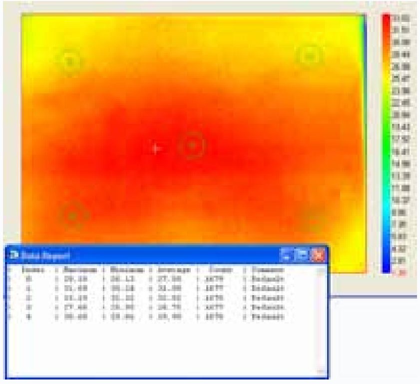
Histogram of luminance



Cross section of color measurement

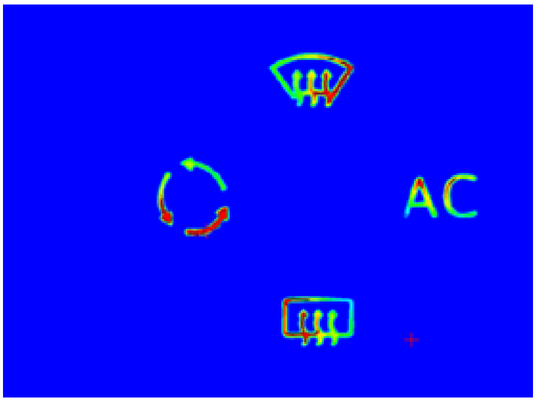


Color testing and color triangle



Analysis with spots

Automotive dashboard testing



Automotive dashboard testing

UMaster *on tripod*

Anything that emits light or requires color testing can be quantified in a matter of seconds.

Inspection automation

User friendly **EZCom** software provided with **UMaster** allows quick and efficient measurement, data analysis and evaluation with easy operation. Measurement recipes can be build easily and recall automatically when needed. Many tools are available for data analysis using **EZCom** software. A panel of OCX component is provided to display and analyze all types of data with custom programming.Automated measurement can be driven using **EZCom** software as ActiveX component. Data transfer is possible in a great variety of format for easy reporting.

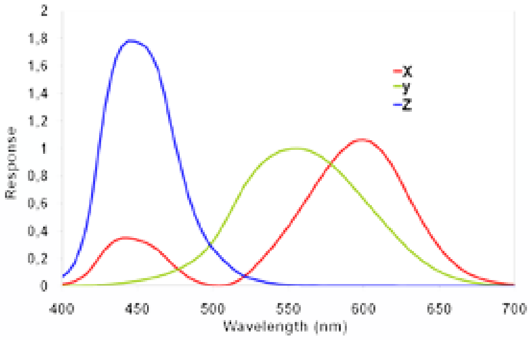
A non exhaustive list of applications with **UMaster**

Display Systems	Illumination Systems
Avonics displays	Automotive head and signal lamps
Automotives displays	Cinema projectors
Backlights	Emergency exit signs
CRT displays	Fiber optic illuminators
Display on-a-chip technologies	Illuminated buttons & switches
DLP projectors	LEDs
LED display modules & signs	Light sources
LCD projectors	Stage lights
LCOS chips	Street lamps
LCOS projectors	Strobe systems
Micro displays	Traffic signals
OLED displays	**Optical components**
PDP displays	Optical filters
RPTV (Rear Screen Projection Systems)	Thin film coatings
TFT/LCD panels	Diffusers and polarizer
TFT/LCD displays	Brightness enhancement films

How to obtain color accuracy ?

The color measurement according to the CIE 1931 document is an integration of the measured light stimuli characterized by its spectral radiance f(λ) multiplied by each of the CIE 1931 curves reported hereafter. In this way we obtain the quantities X, Y and Z given by:

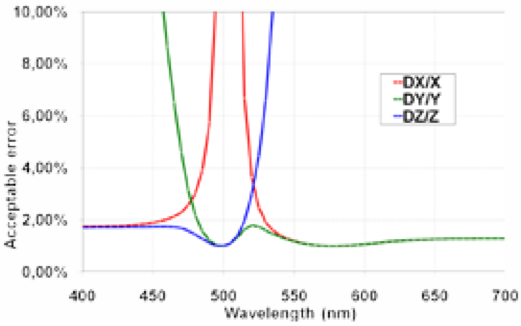
$$X = \int_{360}^{780} x'(\lambda) f(\lambda) d\lambda, \qquad Y = \int_{360}^{780} y'(\lambda) f(\lambda) d\lambda, \qquad Z = \int_{360}^{780} z'(\lambda) f(\lambda) d\lambda$$



Definition of the CIE x'(λ), y'(λ) and z'(λ) curves for color measurements

To obtain color accuracy for any "complex" light sources, it is mandatory that the spectral response of the system fit the x'(λ), y'(λ) and z'(λ) at best. A precise computation of the spectral response accuracy requirements can be carried out. If we consider that the error on the color coordinates δx and δy must be lower than a given value ε, we can show that it is verified when:

$$\frac{dX}{X} < \frac{\varepsilon}{(2x\,(1-x))}, \qquad \frac{dY}{Y} < \frac{\varepsilon}{(2y\,(1-y))}, \qquad \frac{dZ}{Z} < \frac{\varepsilon}{(2z\,(1-z))}$$



Acceptable error on the CIE curves for color accuracy better than 0.005 for the color coordinates x and y

Plotting these curves shows that, except when the response is nearly zero, a maximum error of 1% to 2% is required when ε =0.005 error is targeted on obtained color coordinates. It means that in order to guarantee a significant accuracy a maximum error of a few % is required at each color wavelength on spectral response of the measuring system to follow CIE curves as closely as possible.

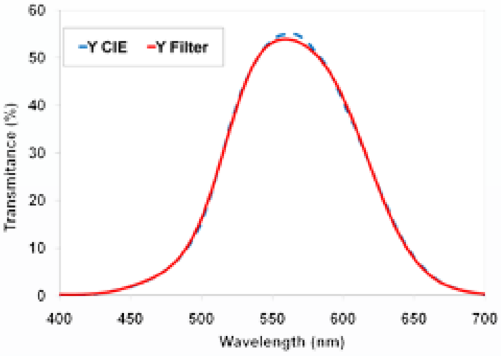
Standard solutions

Systems based on color sensors must be excluded because of the impossibility to adjust the spectral response. Most commercial systems use monochrome sensors and additional color filters but here also great care must be taken to achieve accuracy. **ELDIM** uses in most of its systems a set of 5 color filters designed specifically for each CCD sensor. These filters are realized as a combination of different color glasses that work in absorbance.

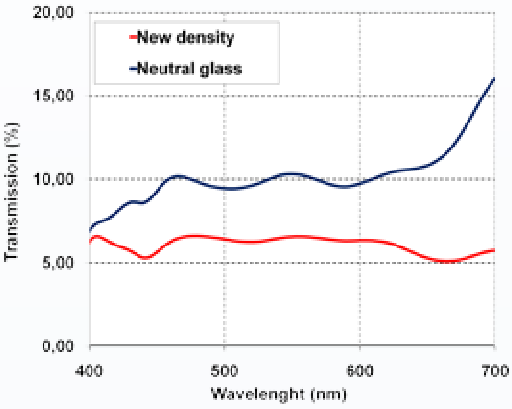
Advantages are very good accuracy because of the adaptation of the design to each CCD sensor and an excellent durability. Main drawbacks are that filters are quite thick, with relatively low transmittance and 5 filters are needed since it is not possible to make Y CIE curve with only one filter.

UMaster improvements

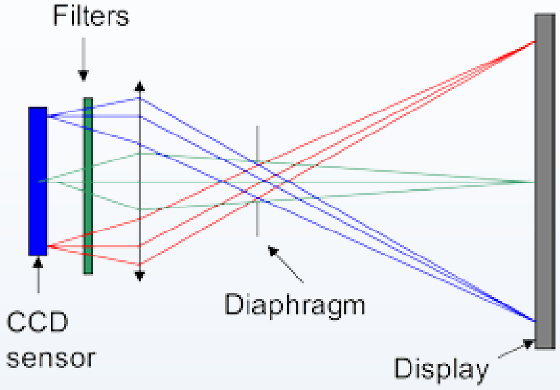
The new filter technology uses transparent thin layer structures deposited on color glasses. These films are deposited by ion assisted electron beam evaporation to ensure stability and reliability. There are adapted to the spectral response of each CCD sensor. Advantages are thinner filters with higher transmittance and only 4 filters (2 for X, 1 for Y and 1 for Z) for similar or better accuracy. The neutral density are also realized with the same technology with better properties than neutral standard glass solutions.



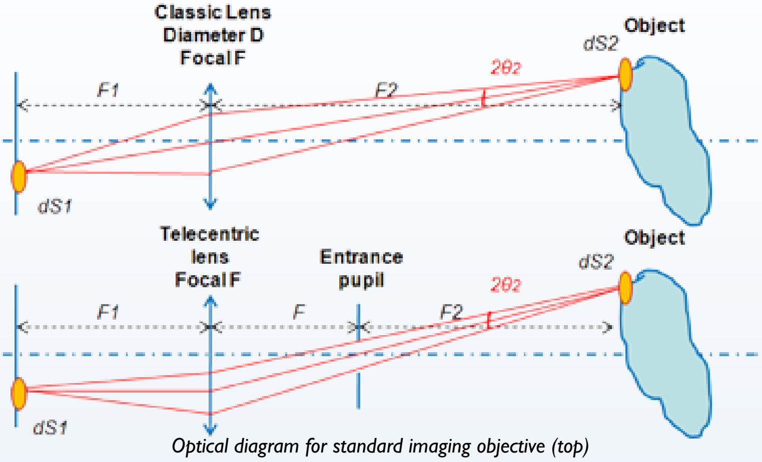
Measured transmittance of a new Y filter based on TiO2/SiO2 coatings



Measured transmittance of a standard neutral glass filter and the new density filter



Principle of the telecentric lens on the sensor side



Optical diagram for standard imaging objective (top) and ELDIM objective telecentric on the senor (bottom)

The imaging optics

For accurate measurements the imaging optic plays a key role. Indeed, standard imaging optics suffer from a dependence of the flux with the distance to the object. One basic "solution" is to provide different sets of calibration for the system with all the possibilities of error that can occur. **ELDIM** uses a much better solution based on telecentric optic on the sensor side. A first obvious advantage is that all the light rays cross the filters with the same incidence what ensures the same spectral response everywhere on the image. Another key advantage is the independence of the flux with the object distance.

Dependence of flux with distance for standard objectives

The flux emitted by an elemental surface dS_2 of luminance L in the small angular cone $2\theta_2$ is given by:

$$d\phi_2 = 2\pi L(1-\cos\theta_2)dS_2 \approx \pi L\theta_2^2 dS_2$$

We want to calculate the flux collected by and elemental surface dS_1 on the detector.

$$d\phi_1 = kd\phi_2 = k\pi L\theta_2^2 dS_2 = M_1 dS_1$$

The conservation of the geometric etendue gives the following relation between the surfaces: $\frac{dS_1}{F_1^2} = \frac{dS_2}{F_2^2}$

Using the relation between F1, F2 and the focal length F# we finally obtain:

$$M_1 = \frac{k\pi LD^2}{4F\#^2}(1-\frac{2F\#}{F_2}) = M_\infty(1-\frac{2F\#}{F_2})$$

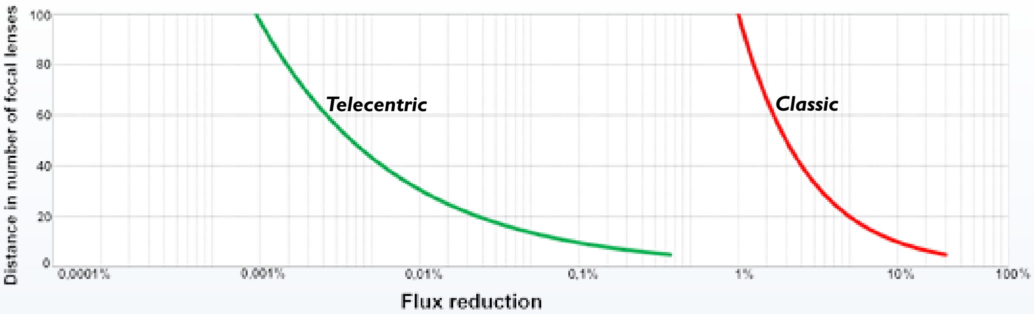
The signal seen by the detector is then dependent on the distance of the object. At 10F# the reduction is about 20% as shown in the figure with a big impact on the accuracy.

Flux stability for telecentric objectives

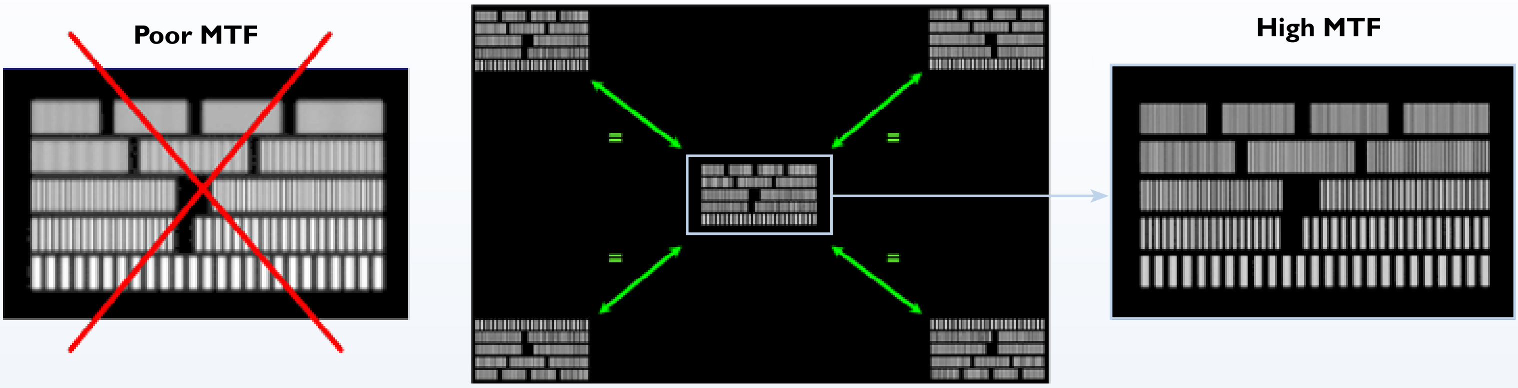
For a telecentric configuration $dS_1/F^2=dS_2/F_2^2$ and M_1 is independent of the distance in first approximation. If we develop the cosines to the third term we can find:

$$M_1 = \frac{k\pi LD^2}{4F\#^2}(1-\frac{3F\#^2}{16F_2^2}) = M_\infty(1-\frac{3F\#^2}{16F_2^2})$$

The figure shows a flux reduction lower than 1% for 5F# distance and lower than 0.1% for 15F#. A single calibration is then sufficient for all practical distances.



Theoretical dependence of the flux with the object distance (standard optics and telecentric optics)



Test patterns measured by **UMaster** *(middle). Marks are correctly resolved up to the third line on all patterns (cf. right). It is not the case with a commercial optic (cf. left).*

MTF and distorsion

The MTF (modulation transfer function) of the sensor is the modulus of the Fourier transform of the PSF (point spread function). The better the equipment is and the smaller the image of a punctual source (PSF) is which means the larger the MTF is. To say it differently the cut off frequency of the MTF needs to be as high as possible. This characteristic of the sensor is directly linked to the optical MTF of the single optics (without CCD and electronics), but also to the CCD pixel size, to the CCD quality and to the electronic chain.

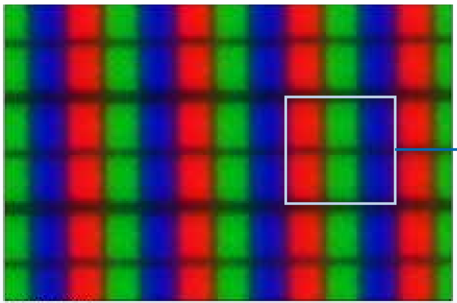
At **ELDIM**, optical designs and production for all equipments are home made. This ensures a high and stable quality for all our optics. **ELDIM**'s low distortion optics ensure a perfect image with minimized optical defect compensations. Most of common equipments compensate for important distortions by software calibration. This allows redressing line images on the border of the image but degrades the global MTF and introduces artifacts in the image. Furthermore, the modulation Fourier Transform (MTF) of our optic is very large since it allows resolving very compact line patterns. On the figure hereafter we compare the resolution of our optic to commercial optics. Also important is the MTF stability ON and OFF axis on the whole field of View. It's easy to obtain an excellent MTF in the middle of the image (ON-axis) when not taking into account the MTF on the border of the field of view (OFF axis). **ELDIM**'s MTF is very stable which means that patterns in the corner of the image are as resolved as patterns in the center of the image.

Additional optics for high spatial resolution

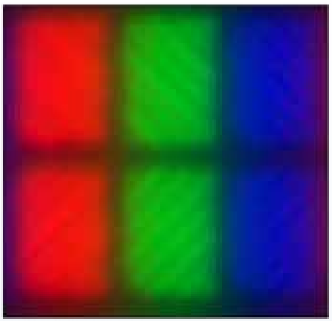
ELDIM offers now a set of additional optics to allow high and ultrahigh spatial resolution measurements of displays at the pixel level. These additional optics image the object on the sensor with a fixed magnification ratio at a fixed working distance. They offer an easy way to get accurate color images at high spatial resolution.

Additional optics	Spatial resolution	Field of view	Working distance
x1	9x9µm	13.5x9mm	59mm
x2	18x18µm	27x18mm	118mm
x4	36x36µm	54x36mm	236mm

Main characteristics of the additional optics for **UMaster with standard optic**



High magnification color image of white state on a LCD



Ultra-high magnification color image of two pixels in white state

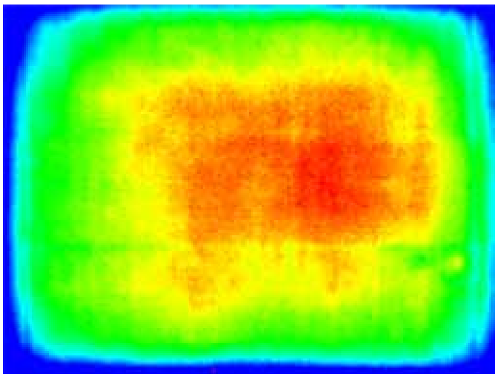
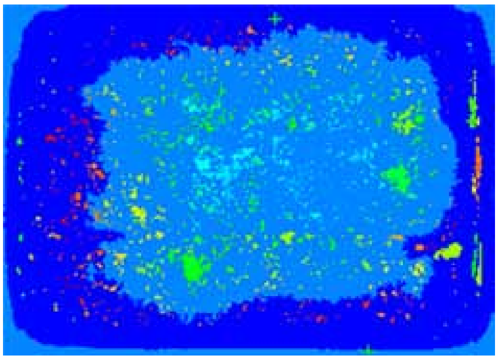
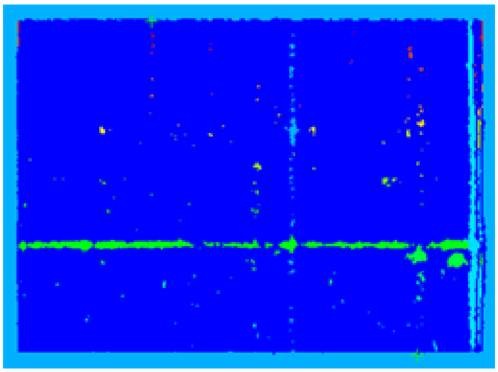


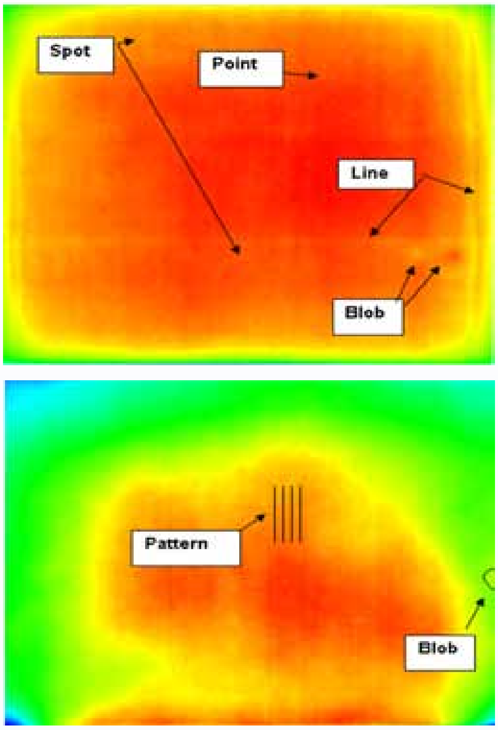
Image of display luminance



Iterative segmentation



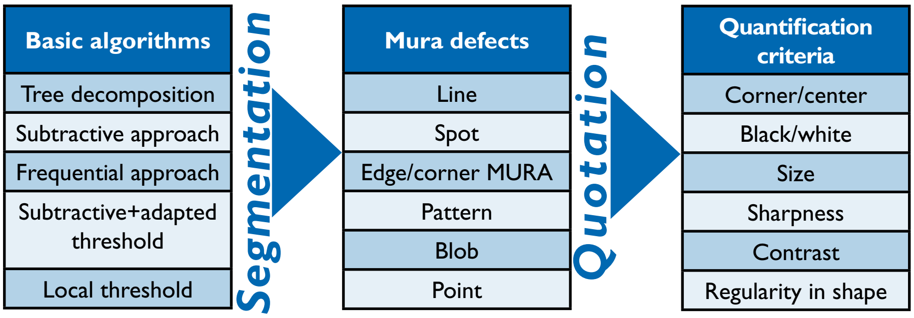
Substractive segmentation



The different families of defect addressed by EZMURA

MURA Defect detection

MURA defect detection requires a high quality sensor since it has to challenge the eyes sensibility which is in many aspects very high. In this respect, **UMaster** is certainly the most sensitive solution of the market thanks to its cooled CCD sensor, high quality optics and high transmission filters. The other difficult task is to automatically analyze, quantify and classify the MURA defects. **ELDIM** provides in option a full automated solution **EZMURA** for this task. The software performs automatically the following operations:



Basic algorithms
- Tree decomposition
- Subtractive approach
- Frequential approach
- Subtractive+adapted threshold
- Local threshold

Segmentation

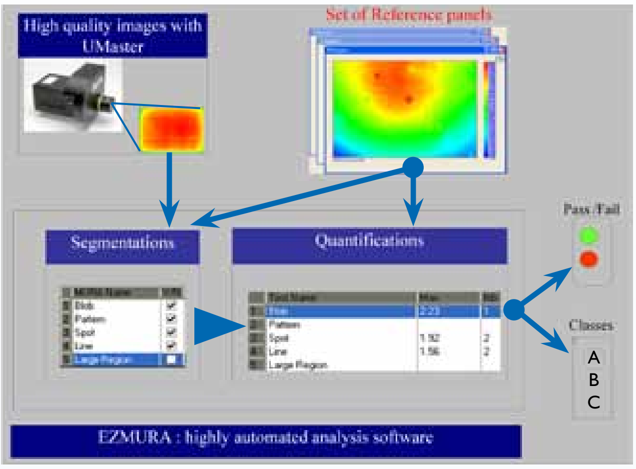
Mura defects
- Line
- Spot
- Edge/corner MURA
- Pattern
- Blob
- Point

Quotation

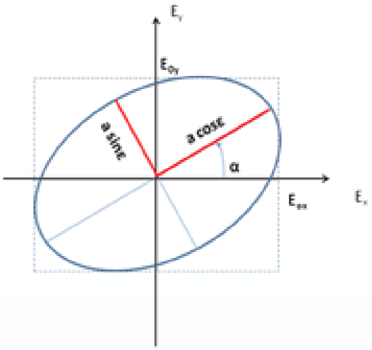
Quantification criteria
- Corner/center
- Black/white
- Size
- Sharpness
- Contrast
- Regularity in shape

Segmentation allows finding defect entities in 2D luminance images from the display. A wide range of segmentation algorithms have been developed: local threshold, region growing, watershed, fuzzy clustering, edge detection, active contour (snakes), Markov random fields, neural networks… Because of MURA family complexity, it is impossible to find a single ideal algorithm able to detect simultaneously all kinds of MURA defects. Each segmentation approach has its own advantages and drawbacks and allows focusing only on a given kind of MURA defect. **EZMURA** software uses six different algorithms to detect different family of MURA defects.

Once a defect has been identified, it has to be quantify so as to decide whether its intensity is acceptable or not. **EZMURA** uses SEMI quantification or custom quantification so as to fit an existing quotation system (based on operator visuals). Critical values can be found (one for each sub classes of defect) and applied for final pass/fail assessment.



Imaging polarization



Definition of elliptic parameters of polarized light

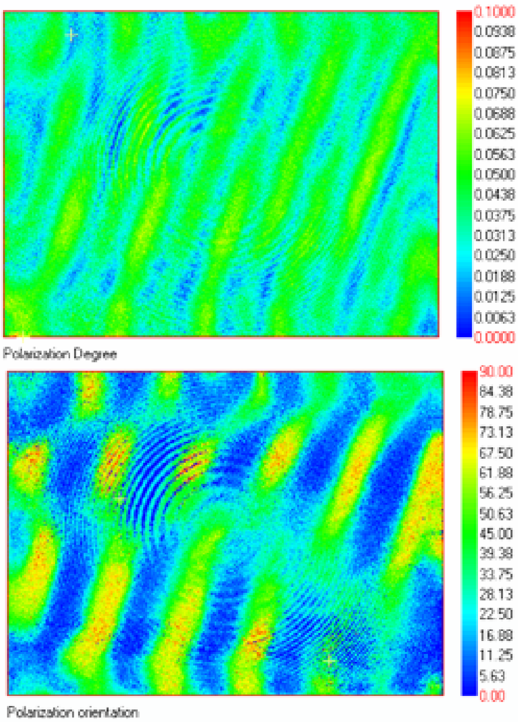
Light can have different states of polarization. It can be randomly polarized (or unpolarized). This is generally the case of natural light. It can be also linearly polarized. In this case the electric field is oscillating always in the same plane. In any case the electric field characterizing any light wave can be separated in two components:

$$E_t = E_{polarized} + E_{unpolarize\ d}$$

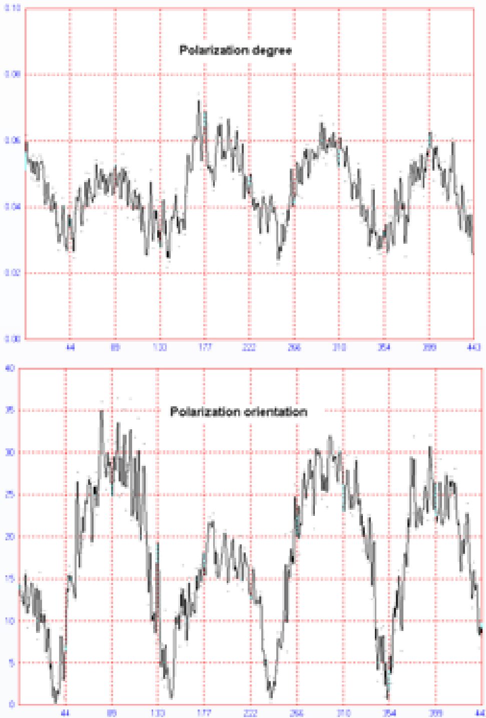
The polarized component can be defined by its elliptical coefficients (ellipticity ε and orientation α) as shown hereafter. Unpolarized light component is defined by the degree of polarization ρ given by the ratio of the intensity due to polarized component over the total light intensity. The three previous parameters can be combined with the intensity to provide Stokes vector.

$$S = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = I.\begin{bmatrix} 1 \\ \rho.\cos 2\varepsilon.\cos 2\alpha \\ \rho.\cos 2\varepsilon.\sin 2\alpha \\ \rho.\sin 2\varepsilon \end{bmatrix}$$

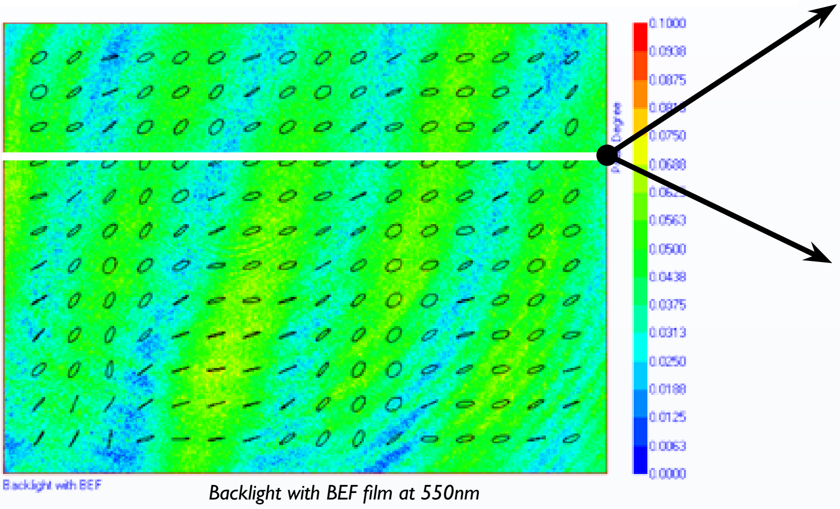
The polarization option of **UMaster** includes three polarizers at different orientations (0, 45 and 90°) and two wave-plates at different orientation (45 and 135°). The system makes automatically seven measurements with different polarization configurations and computes automatically the polarization parameters and the Stokes vectors. The measurement is made at a given wavelength defined by a band pass filter (for example 550nm).
Up to now imaging polarization has not been used to characterize display homogeneity. It is surprising since LCD are essentially polarizer modulators but no practical system was available up to now. **UMaster** covers this gap and allows polarization characterization of displays and their components. For examples CCFL backlights are always partially polarized and can exhibit complex structures on their surface. That will impact the performances of the LCDs.



Polarization degree and polarization orientation of the light emitted by a backlight with BEF film at 550nm

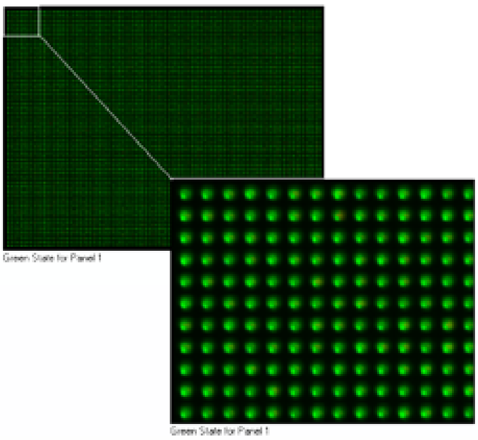


Horizontal cross section of polarization degree (top) and polarization orientation (bottom)



Backlight with BEF film at 550nm

Calibration of LED displays



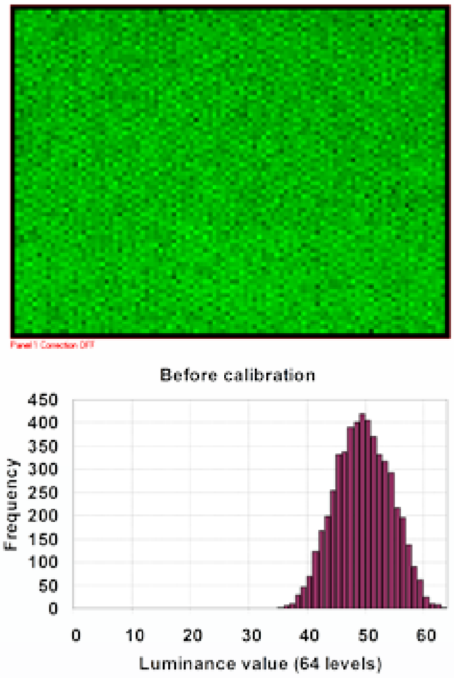
LEDs are located automatically and their luminance and color recorded

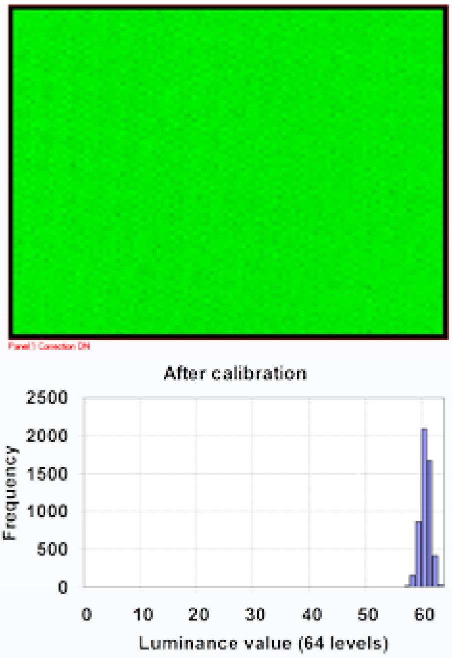
LED displays always suffer from a lack of uniformity because of the dispersion of the LED characteristics. **ELDIM** provides a completely automated solution **LWAP** to calibrate LED display modules in an absolute way. Absolute color measurements are made for each type of LED separately. The software finds automatically all the LEDs on the panel and extracts their color and luminance. It is necessary to define the geometry of the pixel for the calculation of calibration coefficients. One red, one green and one blue LEDs are at least necessary but an additional white LED can be included.

The target color coordinates and luminance for each panel state is converted in tri-stimuli values X,Y and Z. For each pixel the correction matrix C is deduced in order to get:

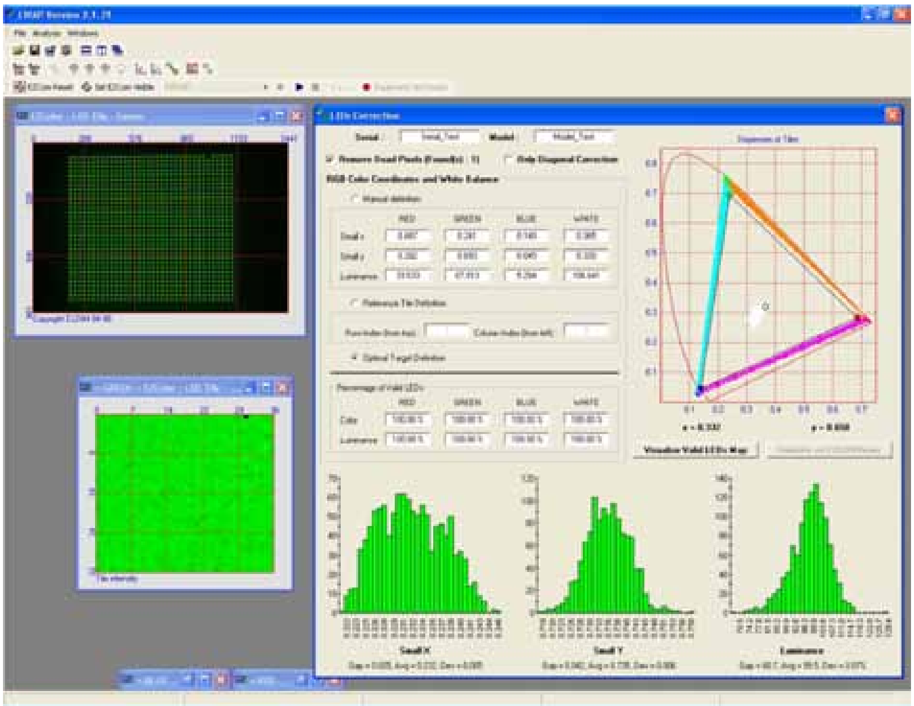
$$\begin{bmatrix} X_{Red}^{Target} & X_{Green}^{Target} & X_{Blue}^{Target} \\ Y_{Red}^{Target} & Y_{Green}^{Target} & Y_{Blue}^{Target} \\ Z_{Red}^{Target} & Z_{Green}^{Target} & Z_{Blue}^{Target} \end{bmatrix} = \begin{bmatrix} X_{Red}^{Meas} & X_{Green}^{Meas} & X_{Blue}^{Meas} \\ Y_{Red}^{Meas} & Y_{Green}^{Meas} & Y_{Blue}^{Meas} \\ Z_{Red}^{Meas} & Z_{Green}^{Meas} & Z_{Blue}^{Meas} \end{bmatrix} \times \begin{bmatrix} C_1 & C_4 & C_7 \\ C_2 & C_5 & C_8 \\ C_3 & C_6 & C_9 \end{bmatrix}$$

LWAP computes automatically the different correction matrixes by solving each set of linear equations and stores them in different formats. Once all the correction coefficients have been written into the tiles, additional **UMaster** measurements combined with color coordinates and luminance extractions can be realized in order to check the efficiency of the calibration method. After correction the panels show a much better homogeneity both in color and luminance.

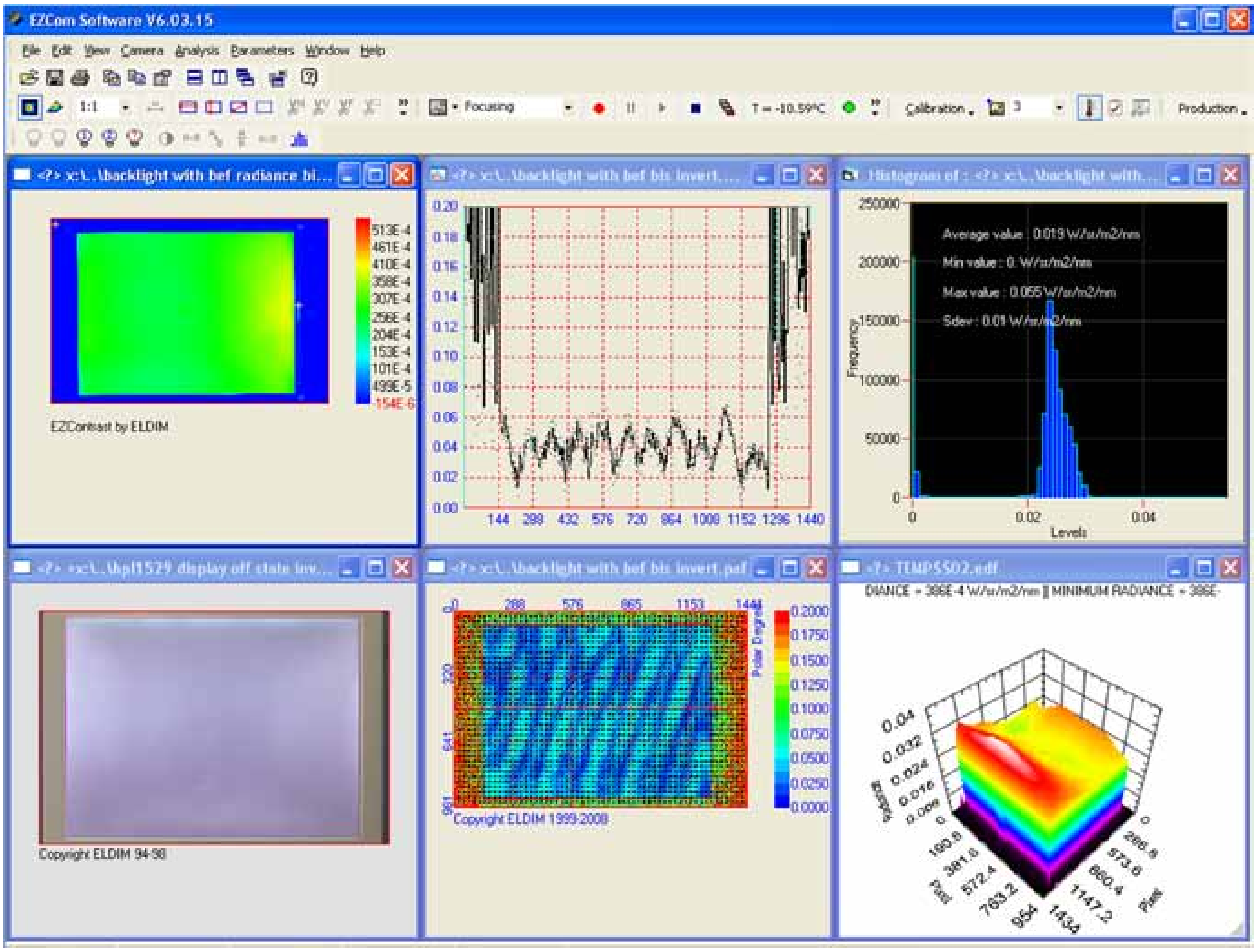




Green color & luminance dispersion before and after calibration.



LWAP software interface for calibration coefficient computation



Average value : 0.019 W/sr/m2/nm
Min value : 0 W/sr/m2/nm
Max value : 0.055 W/sr/m2/nm
Sdev : 0.01 W/sr/m2/nm

DIANCE = 386E-4 W/sr/m2/nm || MINIMUM RADIANCE = 386E-

UMaster comes with a complete software solution for measurement and data analysis.

Some characteristics of the EZCom 6 sofware package for UMaster

Features	Details	Version
Measurement capacities	Imaging Luminance	Standard
	Imaging Color	Standard
	Imaging Polarization	Option
Data analysis	Luminance contrast	Standard
	Color unit: xy, u'v', Lu*v* or La*b*	Standard
	Color intensity, Color Difference, Color Dispersion, Color Triangle, Color Temperature, Equivalent Wavelength	Standard
	Cross section (Horizontal, Vertical and free), Isocurves, False Color representation, 3D representation,	Standard
	Smoothing Filtering, Rotation, Clipping, R.O.I. extraction, Averaging, Contour extraction, Moiré removal	Standard
	Polarization Ellipticity, Polarization orientation and Polarization degree	Option
	Stokes vectors	Option
Data export	Copy to clipboard	Standard
	Save in text and excel format	Standard
	Multi-spots statistics	Standard
Programming capacities	All features can be controlled by OCX interface	Standard
	Examples of automated measurements and analysis provided	Standard
Additional softwares	**EZMURA** for MURA defect detection and quantification	Option
	LWAP for LED wall calibration	Option

Major specifications of UMaster Series

Common specifications		UMaster	Options
Imaging lens	*Telecentric on sensor* *Motorized focusing*	Max 16° Max 8° Software adjustment	Standard Optional Optional
Front entrance iris	*Diameter* *Other diameter*	6mm From 2 to 10mm	Standard Optional
Additional optics		x1 x2 x4	Optional Optional Optional
Color	*4 filters adjusted to the ccd response*	2 for X, 1 for Y and 1 for Z	Standard
Densities	*On automated wheel*	ND0.6, ND1.2, ND1.8, ND2.4, ND3.2	Standard
Pass band filters	*For polarization measurements*	Standard 550nm Any wavelength in visible range on request	-PZ option -PZ option
Polarization	*On automated wheel*	3 Polarizers & 2 quarter wave-plates	-PZ option
Sensor configuration	*Monochrome Peltier cooled CCD grade 1*	3300x2500 or 8.25M pixels	Standard
Luminance range	*Automatic ND selection*	up to 10M Cd/m² more than 10M Cd/m²	Standard Optional
Accuracy	*Luminance* *Chromaticity (x,y) RMS* *Chromaticity (x,y) RMS* *Radiance* *Ellipticity, Orientation , Polarization degree*	±3% for any color stimulus (*1) ±0.003 for A type illuminant (*1) ±0.005 for any color stimulus (*1) ±3% (*2) ±3% (*2)	Standard Standard Standard -PZ option -PZ option
Repeatability	*Luminance* *Chromaticity*	±0.5% for full resolution (*3) 0.001 or full resolution (*3)	Standard Standard
Measurement time	*Luminance* *Color* *Polarization State*	<1.5s (*4) <5s (*4) <15s (*4)	Standard Standard -PZ option
Using condition	*Temperature range* *Humidity range*	0 to 30°C 0-85% non condensing	
Interface	*Compute controlled by OCX components*	USB 2.0	
Power	*Independent Power Supply*	AC adapter (100-240V 50/60Hz)	
Current consumption		90W	
Weight		6Kg	

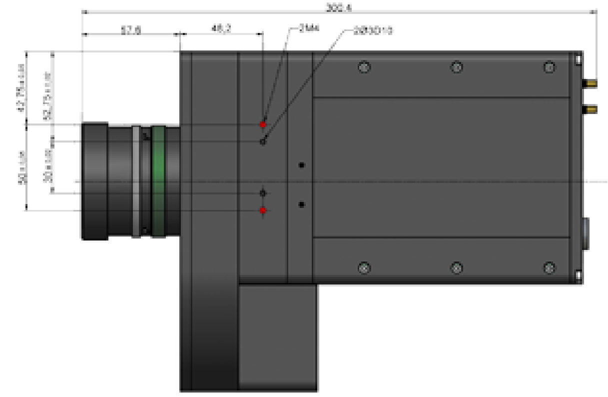
(*1) The accuracy is guarantied for any type of color stimuli in contrast to competitors that generally guaranty only reference white.

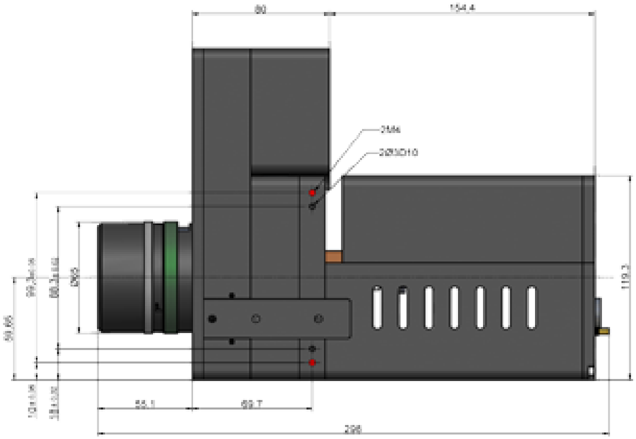
(*2) For a radiance level higher than 10mW/Sr/m²/nm

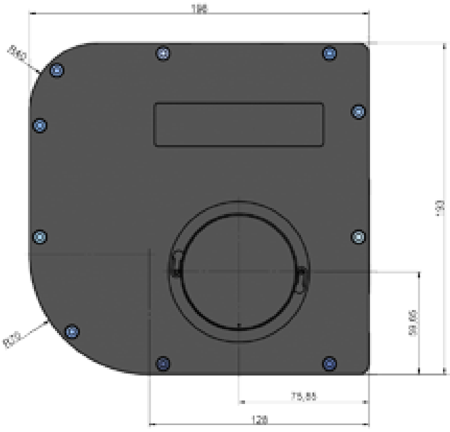
(*3) For a luminance higher than 50Cd/m². This repeatability is given for full resolution. When a binning level N is used it is divided by a factor of N². With standard CCD sensor and for a resolution of 375x250 the luminance repeatability is only ±0.03% !

(*4) Measurement times are highly dependent on the target and on the conditions. Given times are for a source with luminance level higher than 50Cd/m² or a radiance level higher than 10mW/Sr/m²/nm and already determined exposition times for all the filters. Optional neutral densities are controlled independently for all the filters for optimum signal over noise ratio.

Outer dimension (unit mm)







Specifications can be change without notice

RA-02 V3.02 06/2011 ©ELDIM S.A.