


DXOMARK AUTOMOTIVE/ROBOTICS EVALUATION REPORT

--Sample report--

Automotive RGB camera – Standard report

corp.dxomark.com



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P2020 Dynamic Range

Standard compliance

The Dynamic Range measurement is fully compliant with IEEE P2020.

Metric details

The dynamic range measurement is performed on pairs of patches (A, B), with a 2:1 contrast ratio between A and B in the scene

Adjusted CNR (Contrast to Noise Ratio):

$$CNR(A, B) = \frac{s_A - s_B}{\sqrt{\sigma_A^2 + \sigma_B^2}} \cdot \frac{c + 1}{c - 1} \cdot \frac{1}{\sqrt{2}}$$

With:

- s_A, s_B the mean signal of A and B
- σ_A, σ_B the standard deviation of A and B
- c the contrast between A and B in the scene

TCG (Tonal Contrast Gain) is the transfer function between the scene contrast and the image contrast:

$$TCG(A, B) = \frac{\log_2(L_{A,image}/L_{B,image})}{\log_2(L_{A,scene}/L_{B,scene})}$$

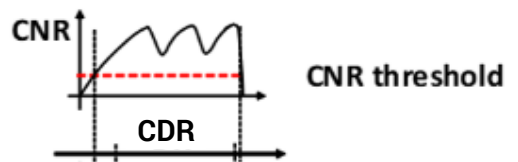
With:

- $L_{A,image}, L_{B,image}$ the mean signal of A and B in the image.
- $L_{A,scene}, L_{B,scene}$ the luminance of A and B in the scene.

CDR (Contrast Detection Ratio) is the dynamic range measured from CNR:

$$CDR_{dB} = 20 \log_{10} \left(\frac{L_{max}[CNR > 1]}{L_{min}[CNR > 1]} \right)$$

With $L_{max}[CNR > 1]$, $L_{min}[CNR > 1]$ the maximum and minimum luminance values that verify $CNR > 1$.



Measurement setup specifications

The dynamic range setup is an assembly of 4 light panels and charts, delivering 25 patches that can reach 170dB dynamic.



P2020 SFR

Standard compliance

The SFR measurement is fully compliant with IEEE P2020.

Metric details

Metrics are computed in 5 different field positions: center and 4 corners of the image.

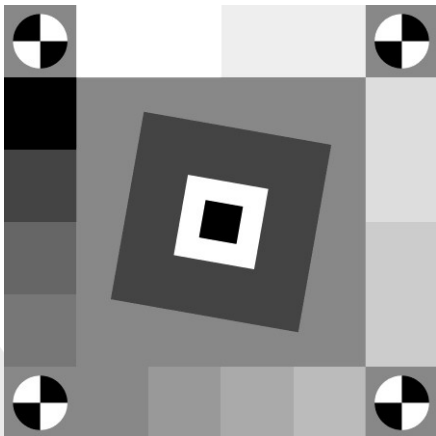
SFR is computed in a linearized image, thanks to the gray patches in the target. The SFR is then averaged over 10 images of the same target to improve the SNR.

- **SFR** curve with frequency in cycles/pixels
- **SFR10** and **SFR50**: frequency (in cycles/pixel) corresponding to SFR=10% and 50%
- **SFR@0.5Nyq** and **SFR@0.25Nyq**: SFR value at frequency = 50% and 25% of Nyquist frequency
- **SfrMax**: maximum SFR value
- **Acutance**
- **Corner Variation SFR50**: relative difference of SFR50 across the 4 corner positions
- **Corner Variation Acutance**: relative difference of acutance across the 4 corner positions

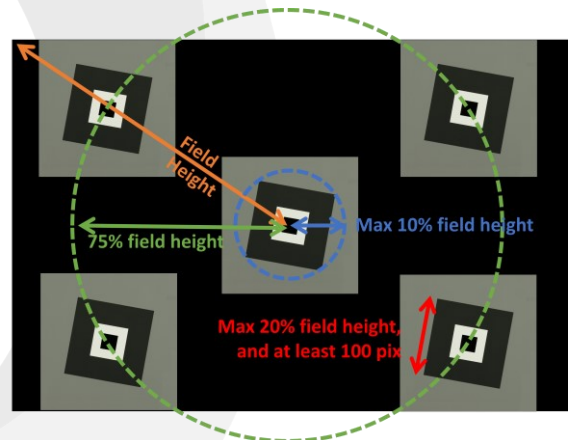
Measurement setup specifications

Slanted square with 10° orientation and contrast 4:1.
Through focus method is used to find the best focus.

SFR chart



5 captured field positions



SFR at Infinity

Standard compliance

The SFR measurement is fully compliant with the standard ISO 12233.

Metric details

A slanted edge is backlit with a collimated light source. This allows the SFR measurement to be performed on devices focused at infinity.

SFR is computed in a linearized image

Metrics are computed in 15 different field positions.

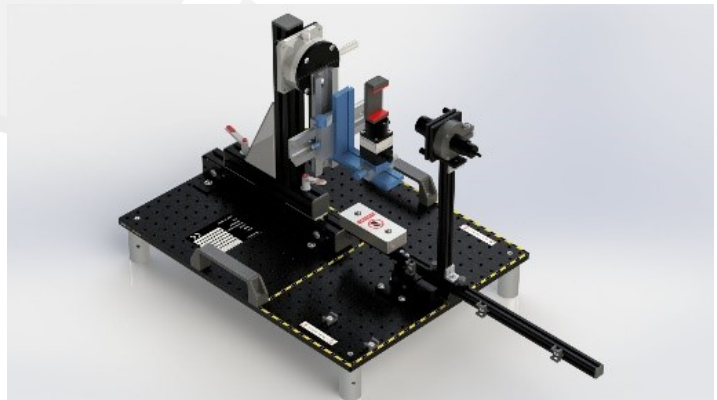
SFR measurement compensates for the collimator reticle MTF during the camera MTF measurement. The collimator reticle MTF is measured compared to a true cutter target.

- **MTF profile:** MTF curve for each field position, with frequency in cycles/pixels
- **Acutance in the field:** acutance values for all tested positions

Measurement setup specifications

COMPASS bench with collimator:

- Focal length: 50 mm
- External diameter: 30 mm
- Reticle: Slanted edge 12 mm
- Aperture: f/2.8
- Motorized arm for rotating the slanted edge between -160° and $+160^\circ$



P2020 Flicker Mitigation

Standard compliance

The flicker mitigation measurement is fully compliant with IEEE P2020.

Metric details

Flicker Modulation Index (FMI):

$$FMI = 100 \times \frac{s_{max} - s_{min}}{s_{max} + s_{min}}$$

With s_{max} and s_{min} the maximum and minimum values of the measured signal for the considered time-range of the video.

Flicker Detection Index (FDI):

$$FDI = P \left[\frac{s(t) - s_{off}}{s_{off}} \geq th \right]$$

Where:

- $P[x]$ is the probability of x .
- $s(t)$ is the measured signal.
- s_{off} is the measured signal when the PWM signal is off.
- th is a minimum threshold above which the LED is considered visible.

Modulation Mitigation Probability (MMP):

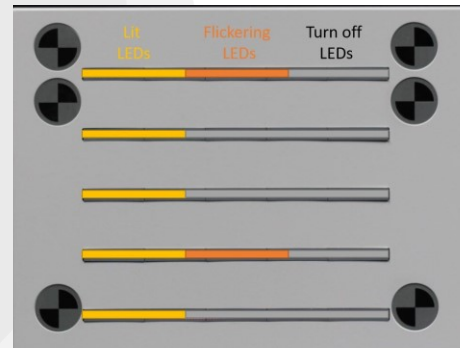
$$MMP = P[\overline{s_{ref}}(1 - \delta) < s(t) < \overline{s_{ref}}(1 + \delta)]$$

Where:

- $P[x]$ is the probability of x .
- $s(t)$ is the measured signal.
- $\overline{s_{ref}}$ is the expected signal.
- δ is a parameter defining the lower and upper bounds of the signal interval in which the device is considered as able to successfully mitigate the LED flickering.

Measurement setup specifications

Flicker is generated by the DXOMARK LED Universal Timer. This device provides a light modulated by a square signal with frequency in range [50, 2000] Hz, adjustable duty cycle, phase and intensity.



P2020 Contrast Performance Indicators (CPI)

Standard compliance

The Contrast Performance Indicators measurement is fully compliant with the standard draft IEEE/P2020 under revision.

Metrics details

The CTA (Contrast Transfer Accuracy) quantifies the ability of a camera to record accurately the contrast in the scene:

$$CTA = P[C_{in} \cdot (1 - \delta_-) \leq C_{meas} \leq C_{in} \cdot (1 + \delta_+)]$$

Where:

- C_{in} and C_{meas} are respectively the input contrast in the scene and the measured contrast in the image.
- δ_- and δ_+ are the parameters defining the lower and upper bound of the confidence interval in which the device is considered as able to reproduce accurately the input contrast.

The CSNR (Contrast Signal-to-Noise Ratio) quantifies the ability of a camera to distinguish two objects:

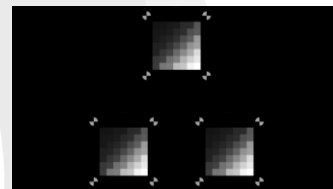
$$CSNR = \frac{\bar{C}}{\sigma_C}$$

Where:

- \bar{C} is the mean of the contrast between two ROIs.
- σ_C is the standard deviation of the contrast between two ROIs.

Measurement setup specifications

The CPI chart is an assembly of 3 light panels, with a 7x7 patches matrix on each chart patches. The whole setup can reach at least 140dB dynamic.



SNR

Metric details

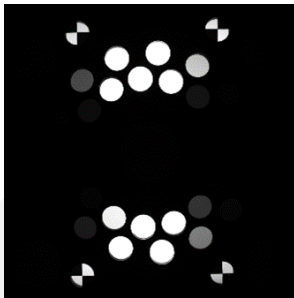
- **Mean signal and noise standard deviation** are computed for each patch
- **Signal-to-noise ratio (SNR)**, computed as:

$$\text{SNR}_{dB} = 20 \cdot \log_{10} \left(\frac{\mu}{\sigma} \right)$$

with μ the mean signal and σ the standard deviation

Measurement setup specifications

DXOMARK HDRNoise target (for manual exposure devices), or calibrite ColorChecker target



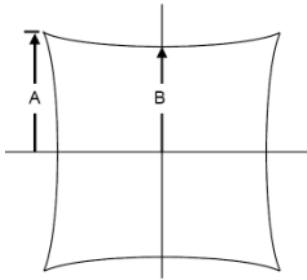
Distortion and lateral chromatic aberration

Standard compliance

The lens distortion measurement is fully compliant with ISO 17850, and the chromatic aberration measurement is fully compliant with ISO 19084.

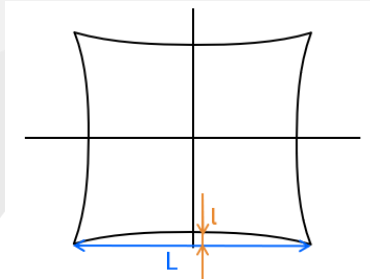
Metric details

TV distortion: $100 \cdot \frac{(A-B)}{B}$, with A and B defined on the following figure:

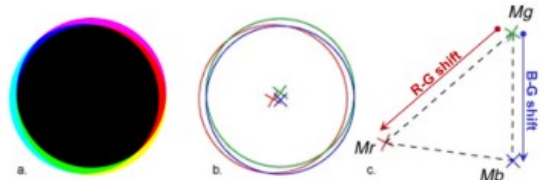


Distortion model reprojection error in pixels and % of of image width, showing the precision of the distortion model.

Geometric distortion: $100 \cdot \frac{l}{L'}$ with l and L defined on the following figure:



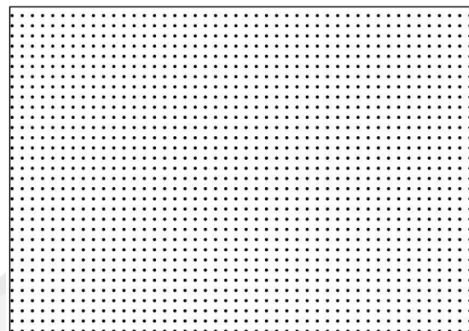
Chromatic aberrations: shift between R and G, and between B and G



Definition of chromatic aberration profiles

Measurement setup specifications

Glass-supported dot chart, offering a very flat surface: less than 1mm planarity difference between the center and the corners of the chart.



Vignetting and Color Lens Shading

Standard compliance

The Vignetting/Color Lens Shading measurement is fully compliant with the standard ISO 17957.

Metric details

Vignetting:

- **Vignetting Profile:** gray level value divided by the gray level value at the vignetting center, for each radial field position and each color channel.
- **Max attenuation:** $\max(1 - \text{VignettingProfile}) \times 100$
- **Max amplification:** $\max(\text{VignettingProfile} - 1) \times 100$

Color Vignetting:

- **Color Vignetting Profile:** each channel vignetting divided by green (average of G1 and G2 channels for raw images).
- **Max Attenuation:** $\max(1 - \text{ColorVignettingProfile}) \times 100$
- **Max Amplification:** $\max(\text{ColorVignettingProfile} - 1) \times 100$
- **Green Imbalance (raw images only):** maps of the relative difference between G1 and G2 channels.

Measurement setup specifications

Litepanels Gemini LED panel or Integrating sphere RO-LIS-3CR80



Texture Preservation

Standard compliance

The Texture measurement is fully compliant with IEEE CPIQ 1858.

Metric details

The measurement is performed on a display-referred linearized image

Acutance

- **Texture acutance:** acutance measured on the textured patch
- **Edge acutance:** acutance measured on slanted edges

Visual Noise

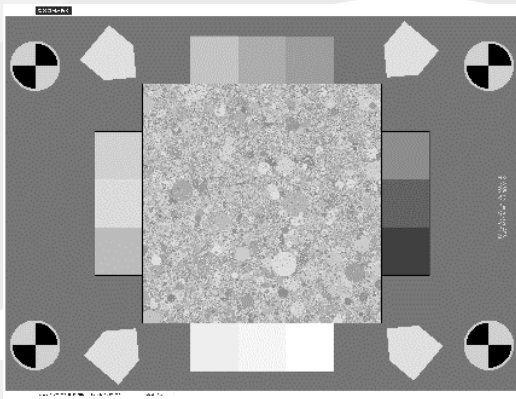
$$\text{Visual Noise} = 6.87 \cdot \log_{10}(1 + \sigma_{L^*}^2 + \sigma_{a^*}^2 + \sigma_{b^*}^2)$$

measured for $L^* = 50$

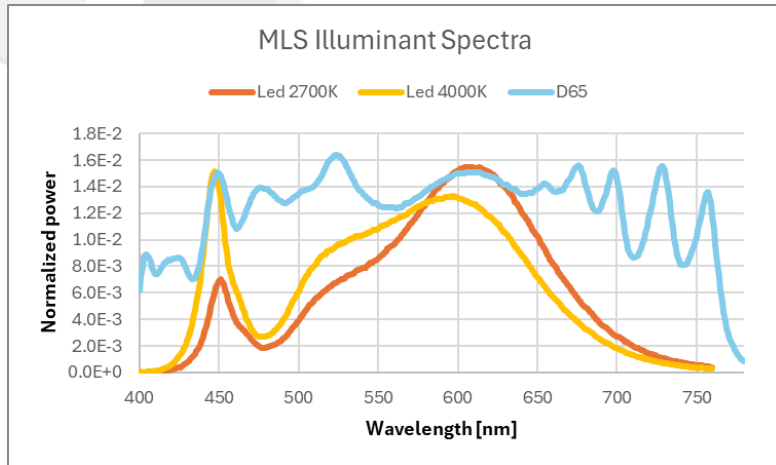
Reference article: *F. Cao, F. Guichard, and H. Hornung. "Dead leaves model for measuring texture quality on a digital camera." Digital Photography VI. Vol. 7537. SPIE, 2010.*

Measurement setup specifications

Texture chart



The MLS allows to reproduce precisely the spectra of the different use cases.



Color Fidelity

Standard compliance

The Color Fidelity measurement is fully compliant with ISO 17321-1:2012, and uses the colors spaces and Euclidean distances defined in the CIELAB specifications emanated in ISO 11664-4:2019.

Metric details

CIELAB is a color space designed to be hue-linear and perceptually uniform. The color fidelity measurement converts the measured image into this color space and compares measured values to the CIELAB ground truth.

Metrics are computed without exposure or white balance correction

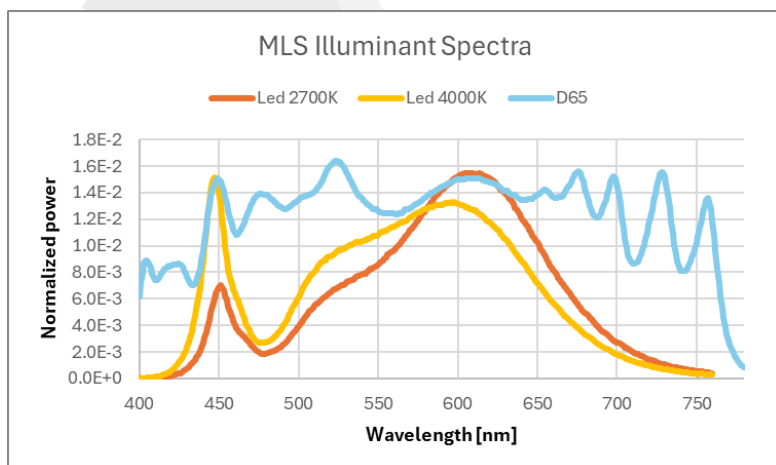
- **Color rendering:** average Δa^*b^* value on all colored patches
- **White balance accuracy:** average Δa^*b^* value on the 4 gray patches (excluding black and white patches)
- **Color rendering map:** the squares represent the CIELAB reference values for each colored patch. The end of the arrows represent the corresponding measured Δa^*b^* value

Measurement setup specifications

24 patches calibrite ColorChercker chart



The MLS allows to reproduce precisely the spectra of the different use cases.





Chip total size	165x40x35 mm
Pixel size	2 μm
Max resolution	3840 x 2160
Full frame rate	36 fps
Lens FOV (H)	105°
Sensor format	1/1.7"
Shutter control	Rolling shutter

Testing Conditions

Mode sensor	Default
Frame Grabber	vRGB-E2s
SW version	13.12
Output	RGB

Framerate	30 fps
Image resolution	3840 x 2160
Exposure time (ms)	16
Gain	8

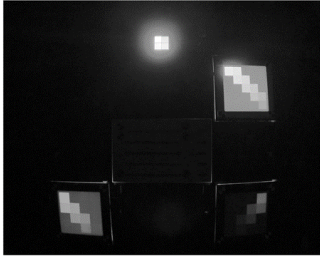
Overall Performance

Center acutance	0.72
Corner acutance	0.62
Max vignetting attenuation	26%
TV distortion	-47%
Chromatic aberrations	< 1 pixel

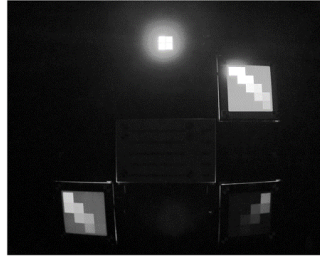
DR P2020	108 dB
Mid-dynamic SNR	33dB
Average flare at 0°	-36dB
Visual Noise (D65 100 lux)	1
Color rendering Δa*b* (D65 100 lux)	22

Image preview with different amplification factors

Clipped at 6.4e+04 cd/m²



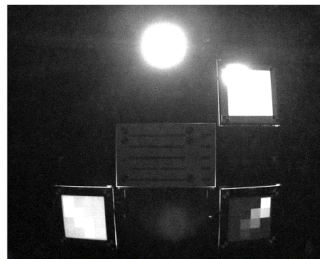
Clipped at 6.6e+02 cd/m²



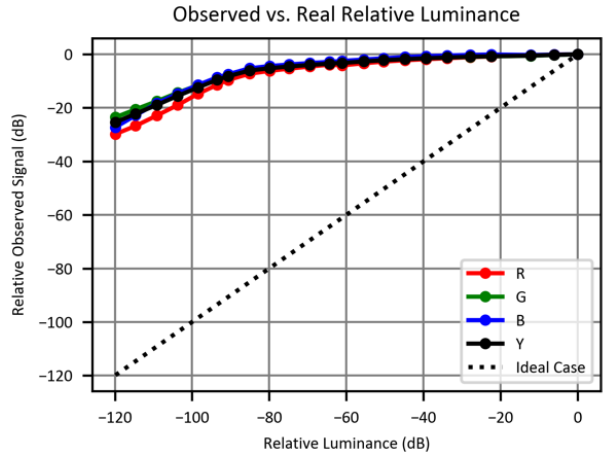
Clipped at 2.1e+01 cd/m²



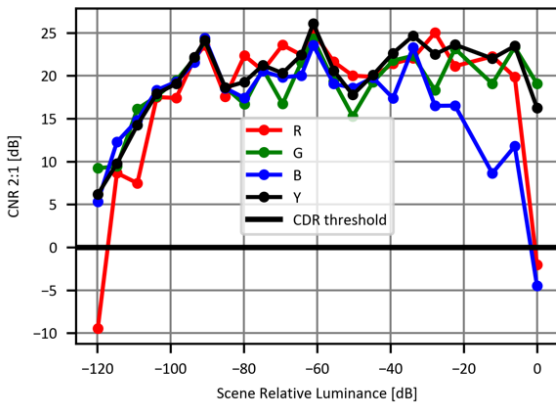
Clipped at 1.0e+00 cd/m²



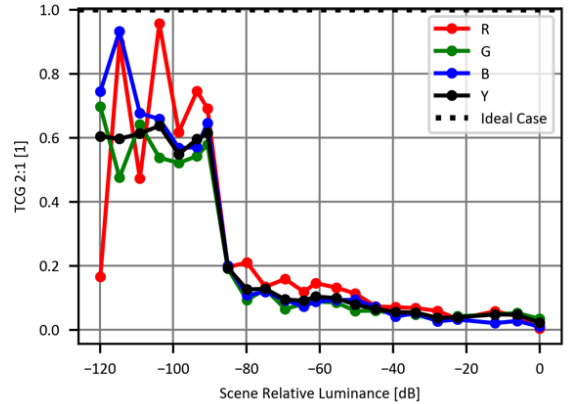
123dB setup with maximum scene luminance 64000 cd/m²



Adjusted Contrast-to-Noise Ratio vs Relative Luminance

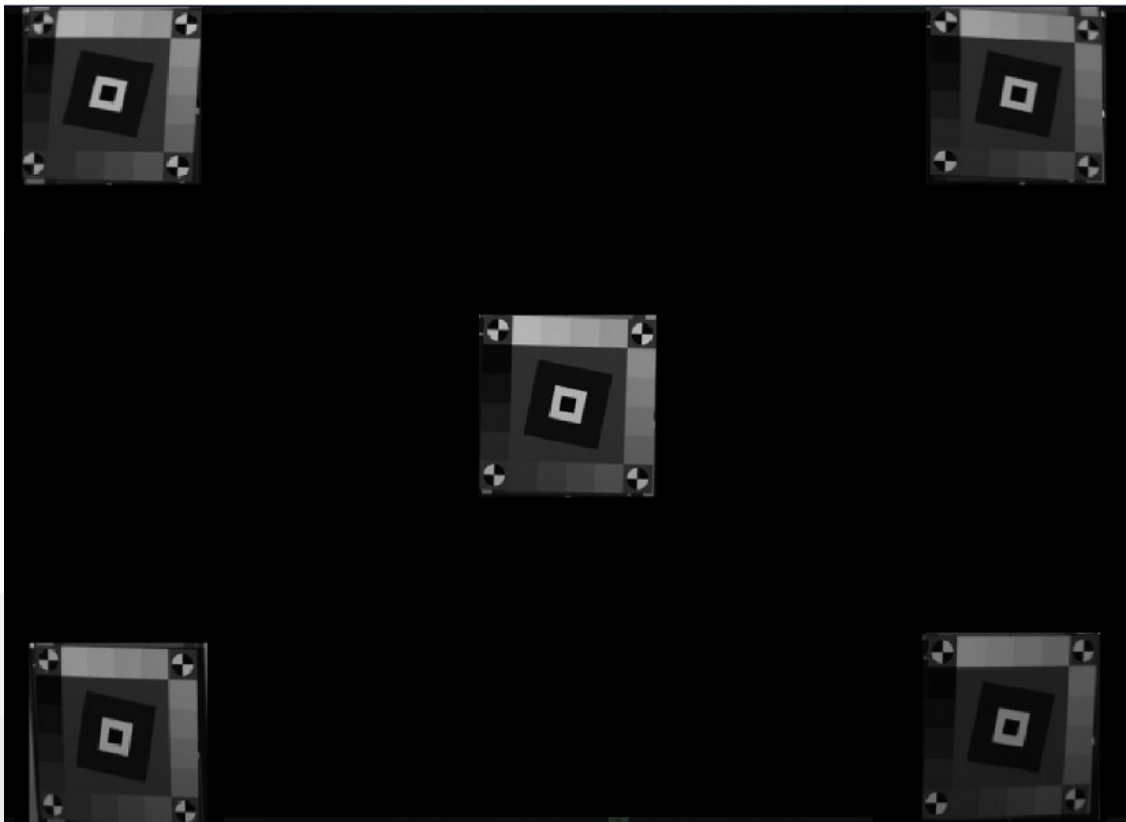


Tonal Contrast Gain vs Relative Luminance



	R	G1	B	G2
CDR (dB)	117 dB	120 dB	118 dB	120 dB

The measurement is performed for different positions in the field of view of the device:

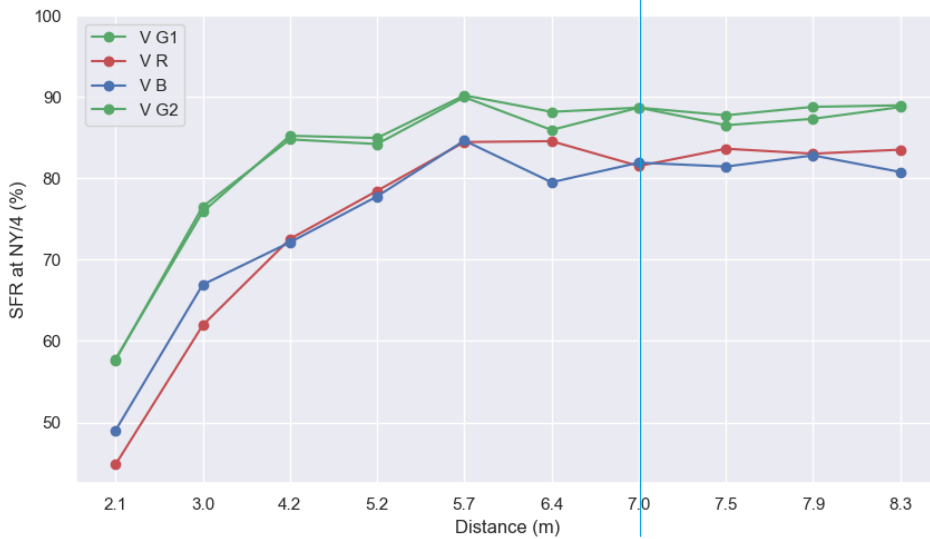
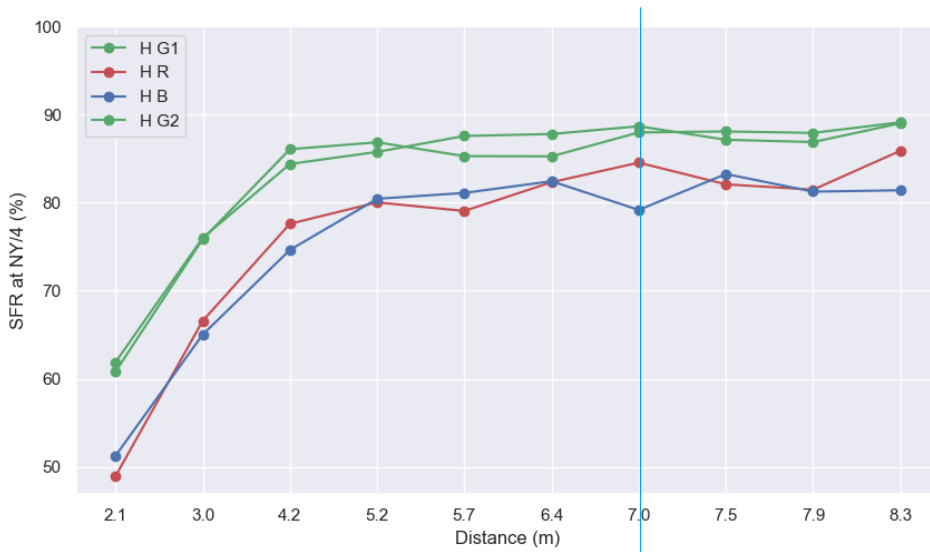


• **Measurement conditions:**

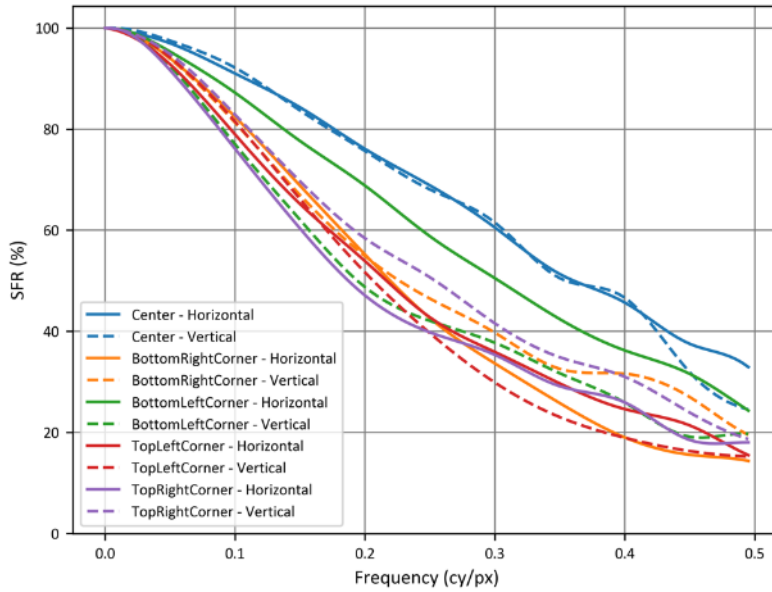
- Illumination: D65 360lux
- Through focus to find the best sharpness in the center
- DUT to chart distance: 7m
- Number of images averaged: 30
- Viewing condition for acutance computation:
 - Distance: 600mm
 - pixel pitch: 0.254mm

- Through Focus

- Chosen position for best focus is 7m.



- MTF at 7m, chart illumination : D65 360 lux



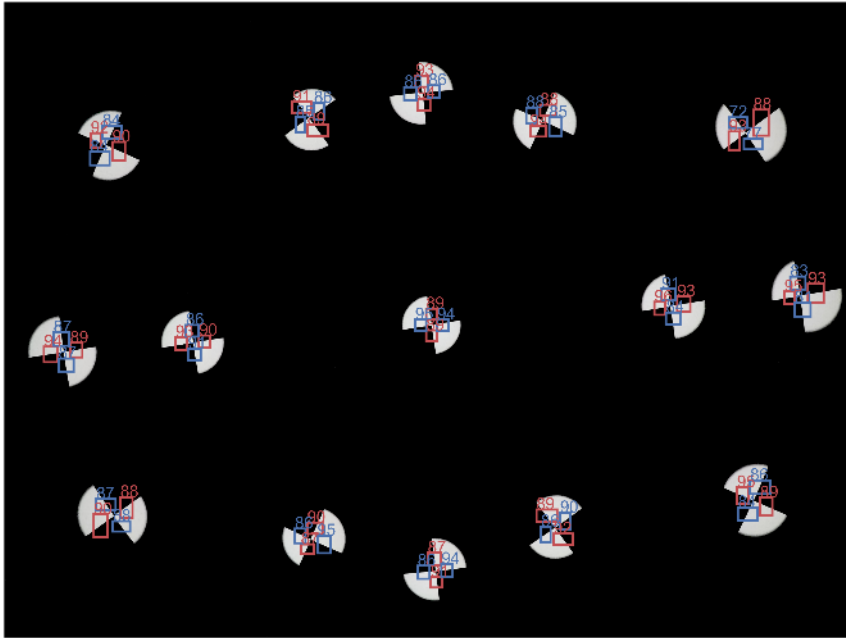
	Center Horizontal	Center Vertical
SFR 10% in cy/px	nan	nan
SFR 50% in cy/px	0.36	0.35
Acutance in %	83	83
SFR@0.5Nyq in %	69	68
SFR@0.25Nyq in %	88	88
SFRMax in %	100	100

	Horizontal	Vertical
Corner Variation SFR50 in %	38	24
Corner Variation Acutance in %	16	8

	TopLeftCorner Horizontal	TopLeftCorner Vertical	TopRightCorner Horizontal	TopRightCorner Vertical
SFR 10% in cy/px	nan	nan	nan	nan
SFR 50% in cy/px	0.22	0.21	0.19	0.25
Acutance in %	68	68	66	72
SFR@0.5Nyq in %	43	40	40	51
SFR@0.25Nyq in %	72	74	68	76
SFRMax in %	100	100	100	100

	BottomRightCorner Horizontal	BottomRightCorner Vertical	BottomLeftCorner Horizontal	BottomLeftCorner Vertical
SFR 10% in cy/px	nan	nan	nan	nan
SFR 50% in cy/px	0.22	0.23	0.30	0.19
Acutance in %	70	70	78	67
SFR@0.5Nyq in %	43	46	59	42
SFR@0.25Nyq in %	76	74	82	69
SFRMax in %	100	100	100	100

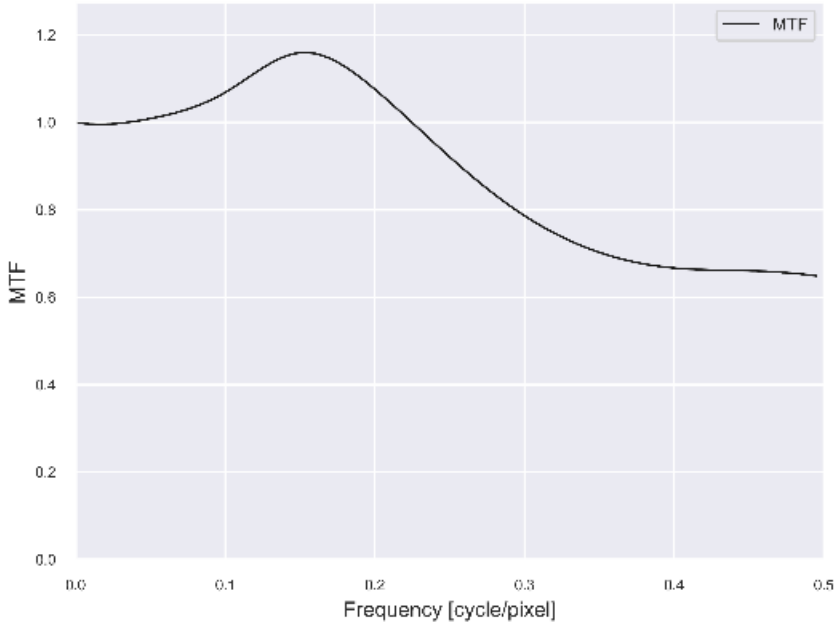
The measurement is performed for different positions in the field of view of the device:



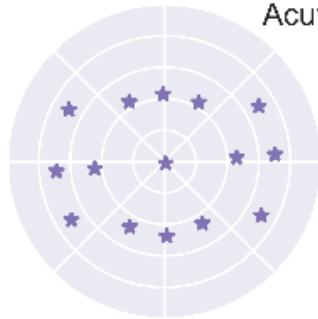
- **Measurement conditions:**

- Slanted edge at infinity
- Viewing condition for acutance computation:
 - Distance: 600mm
 - Pixel pitch: 0.254mm

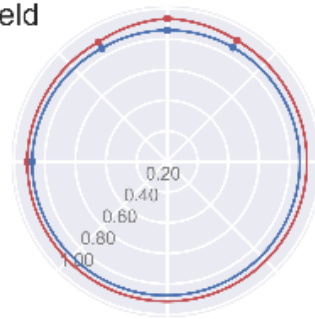
MTF profile at center



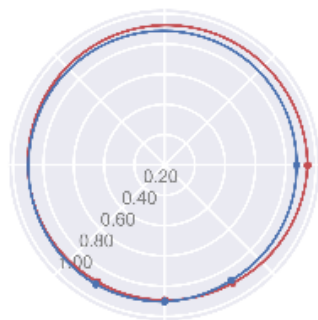
Measured positions in the image



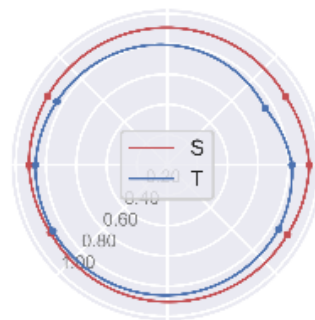
Acutance in the field



52 % of the field



72 % of the field



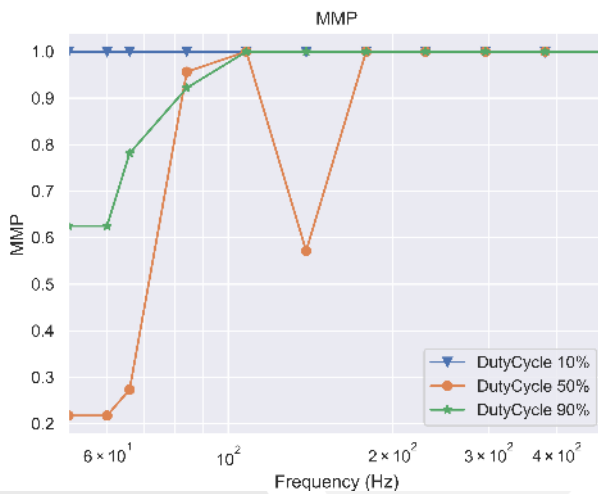
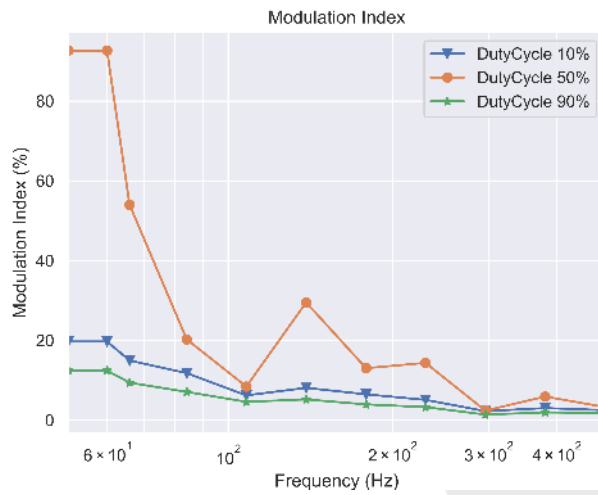
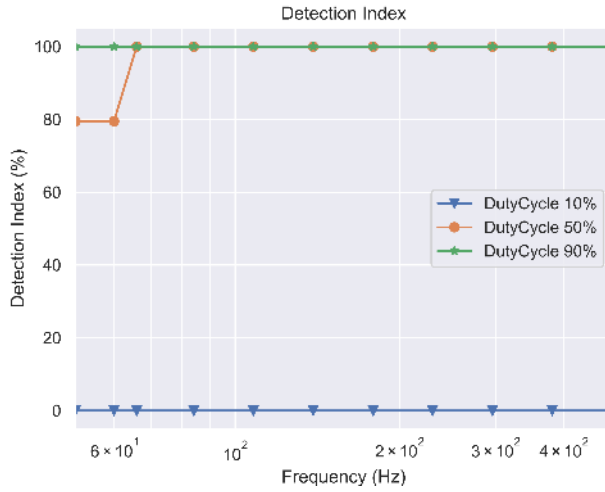
• Measurement conditions:

- 10 LED PWM frequencies in Hz: 50, 51, 60, 66, 84, 108, 139, 179, 230, 296, 381, 490
- 3 LED PWM duty cycles: 10%, 50%, 90%
- 3 test conditions:
 - Background at 10000 lux, LED light intensity at 3000 cd/m²
 - Background at 180 lux, LED light intensity at 90 cd/m²
 - Background at 0.5 lux, LED light intensity at 6 cd/m²

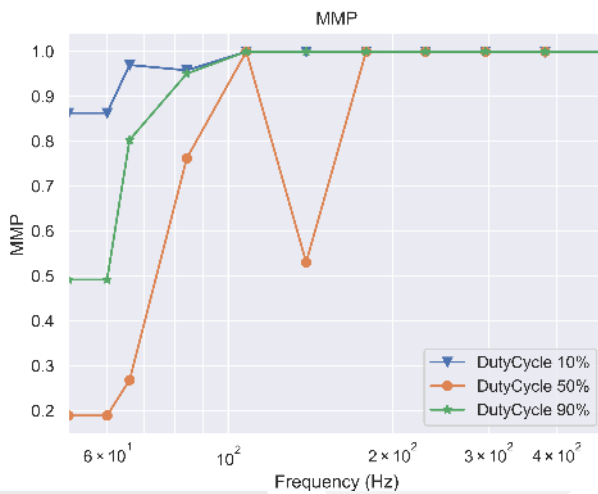
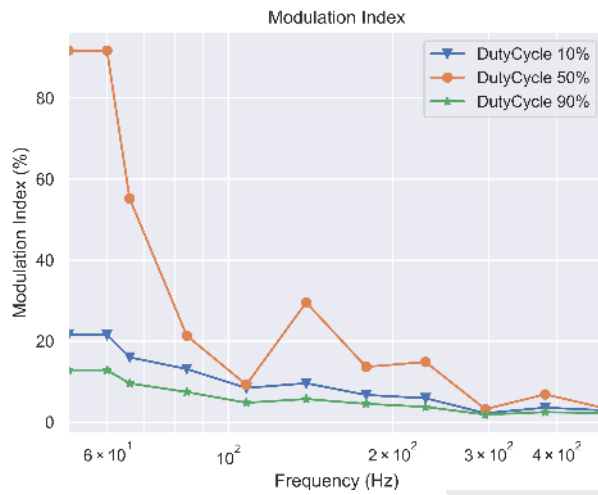
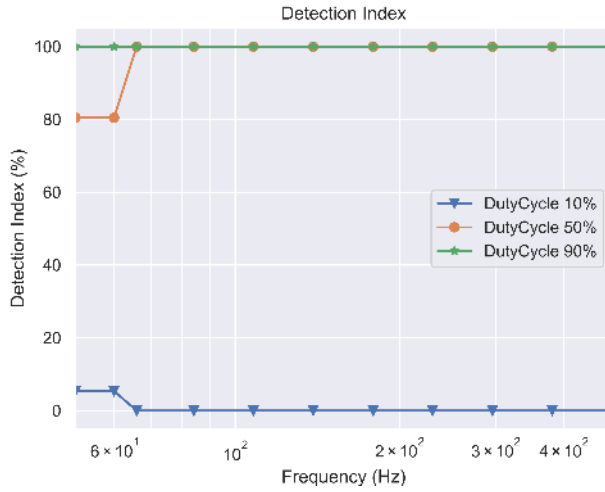
• Results:

- The exposure time is 10ms:
 - Significant flickering for frequencies below 100Hz (1 / exposure time)
 - Limited flickering for high frequencies
- No other visible LED flicker mitigation effect
- The response to flickering is the same for the 3 tested lighting conditions

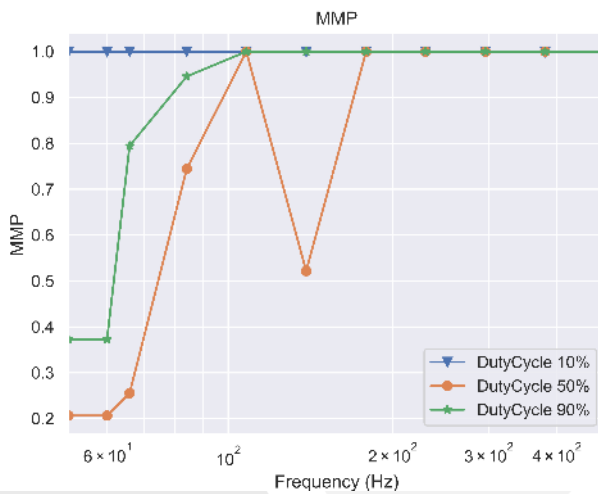
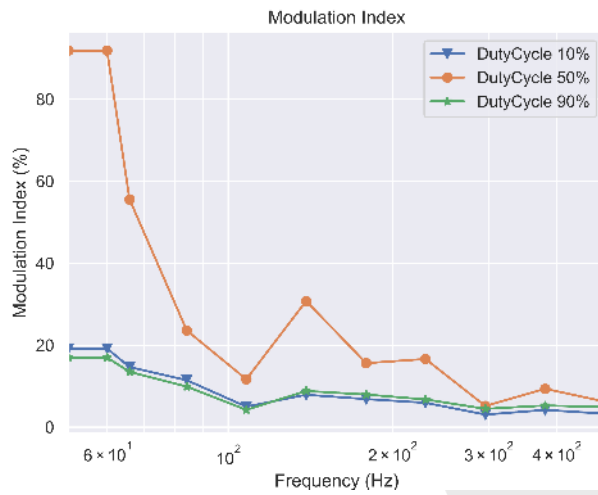
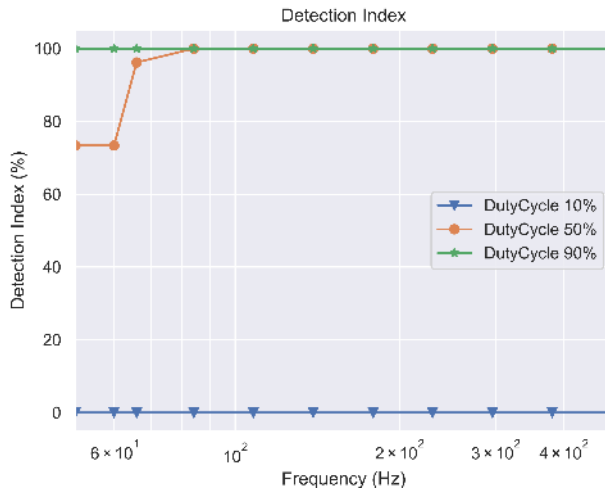
Background at 10000 lux, LED light at 3000 cd/m²

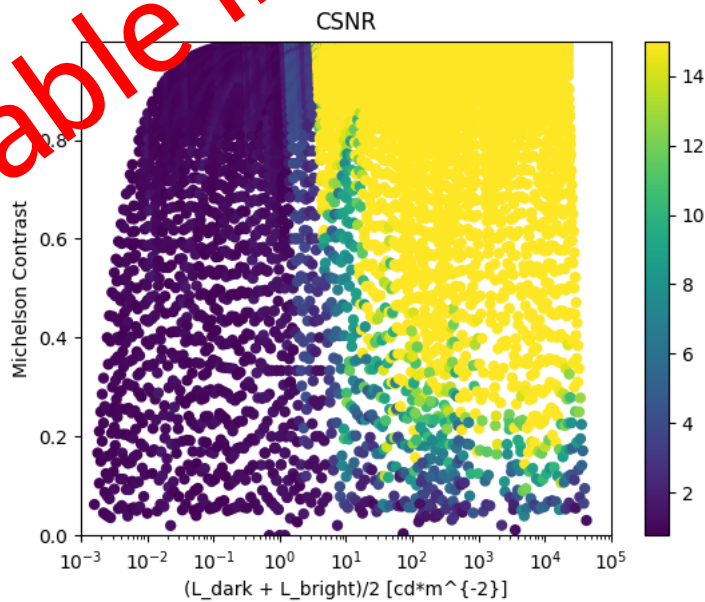
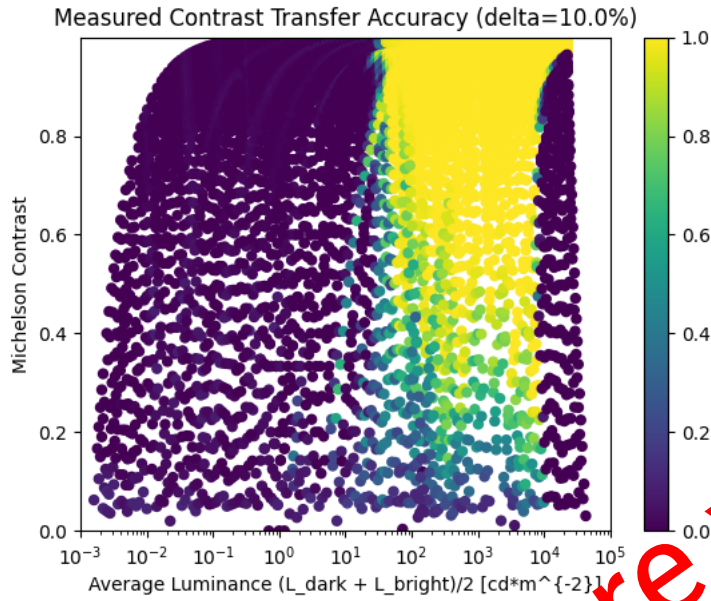


Background at 180 lux, LED light at 90 cd/m²

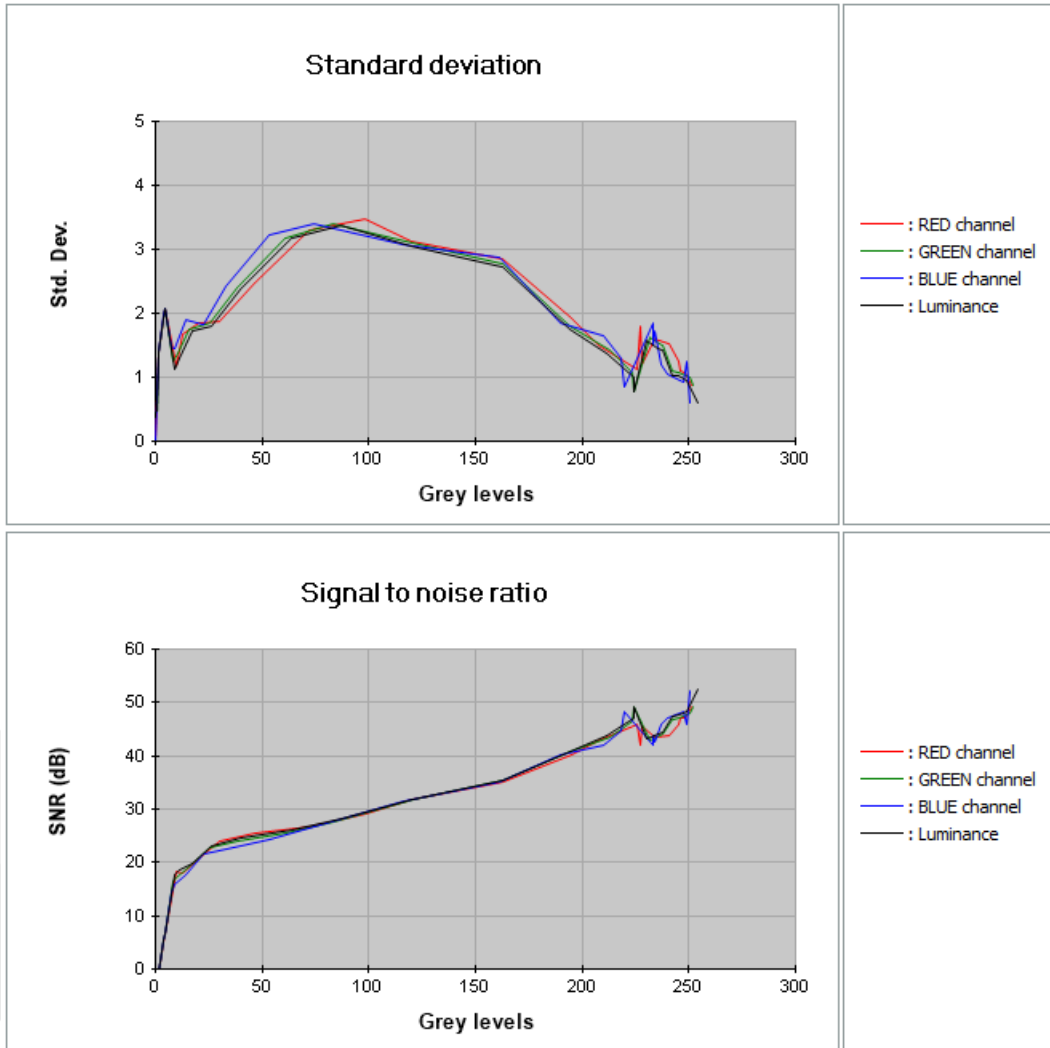


Background at 0.5 lux, LED light at 6 cd/m²



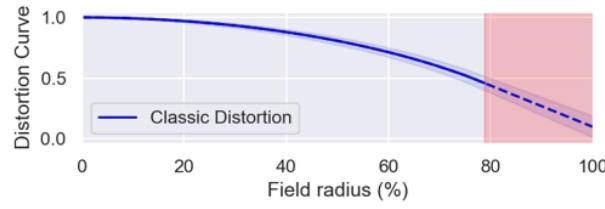
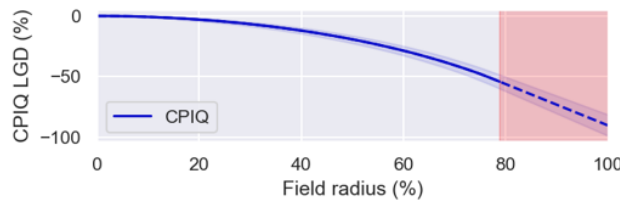
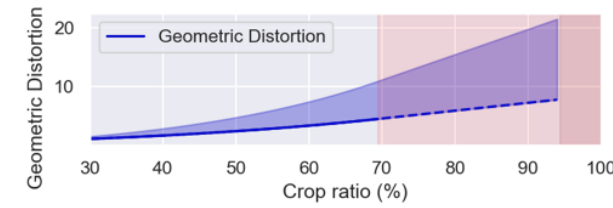
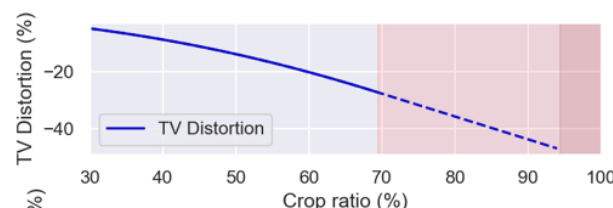
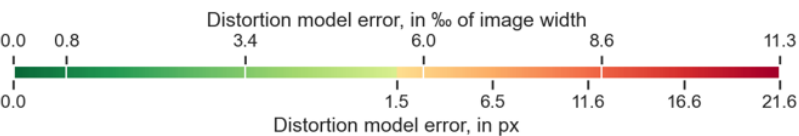
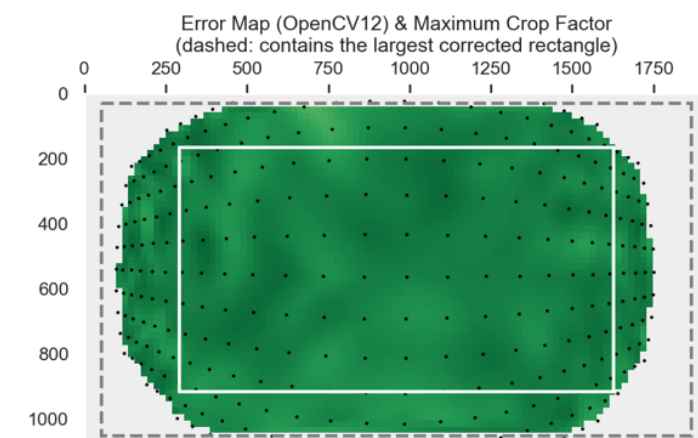
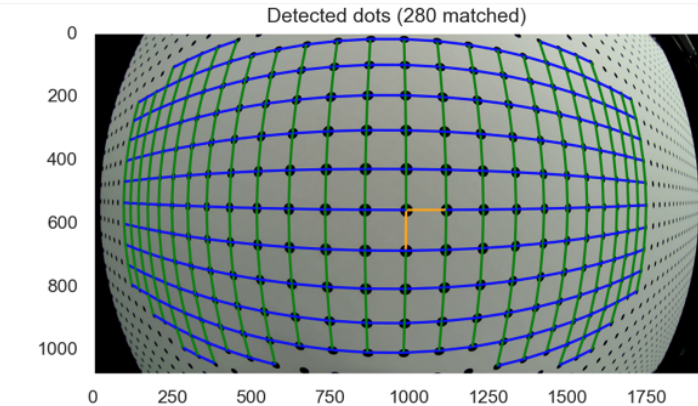


Available in a future version



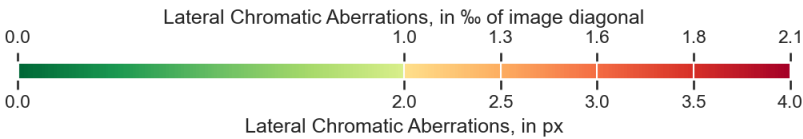
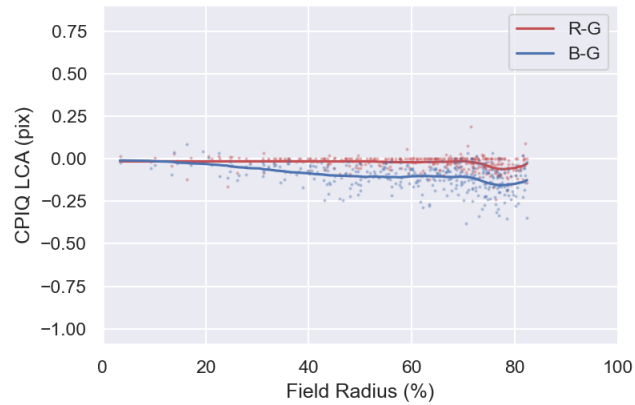
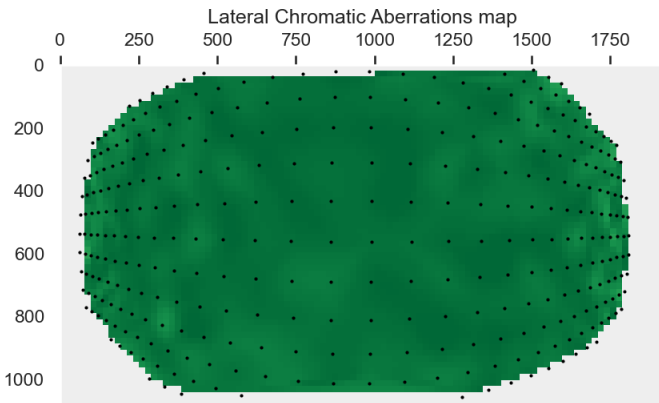
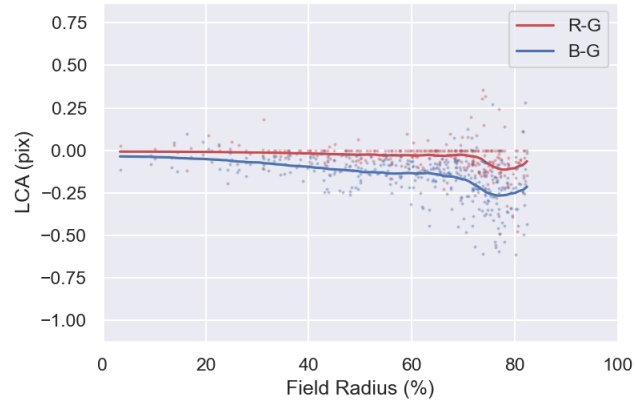
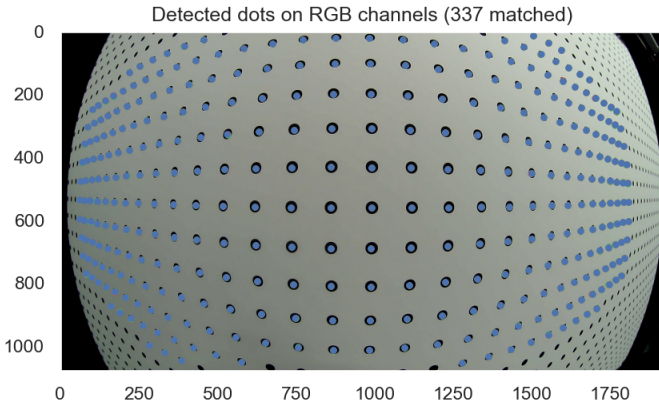
SNR for Grey Level = 128 (interpolated from measurement results)

	R	G	B	Y
SNR (GL=128)	32.3 dB	32.5 dB	32.5 dB	32.6 dB



	Results	Results (non extrapolated)
TV Distortion	-46.83%	-27.27%
Geometric Distortion (avg)	+7.81%	+4.55%
Geometric Distortion (Max)	+21.48%	+11.00%

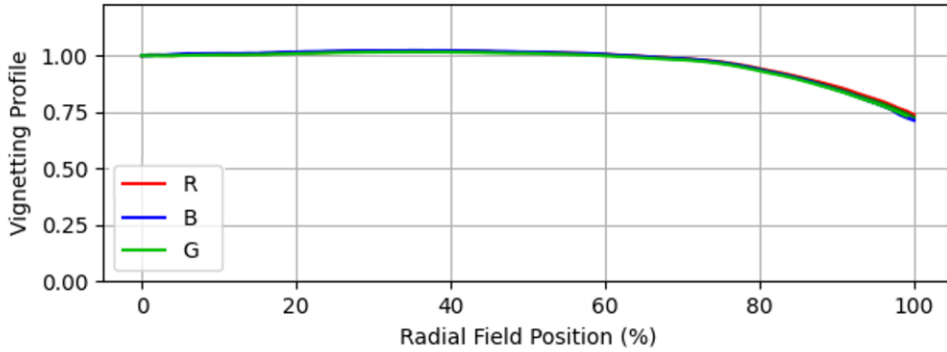
Good fitting of the distortion model (small reprojection error)



CPIQ Max LCA (Pixels)	-0.15 px
CPIQ Max LCA (Percent)	-0.01 %
CPIQ Max LCA (JND)	0.00

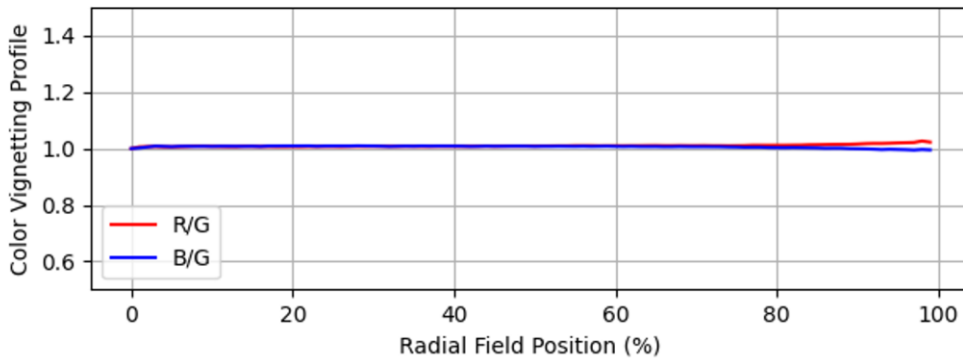
Chromatic Aberrations are negligible (less than 1 pixel in the full measurement area)

Vignetting



	R	G	B
Max Attenuation	24.5 %	25.6 %	27.5 %
Max Amplification	2.0 %	2.0 %	2.3 %

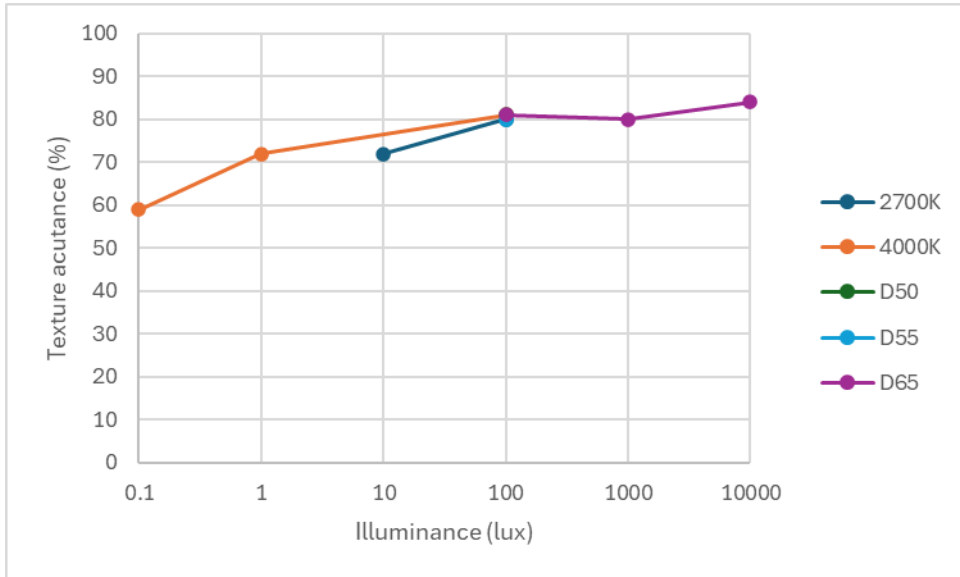
Color Lens Shading



	R	B
Max Attenuation	0.8 %	2.3 %
Max Amplification	3.5 %	2.4 %

Vignetting Measurement done with illuminant D50
Results: Good vignetting and color lens shading performance

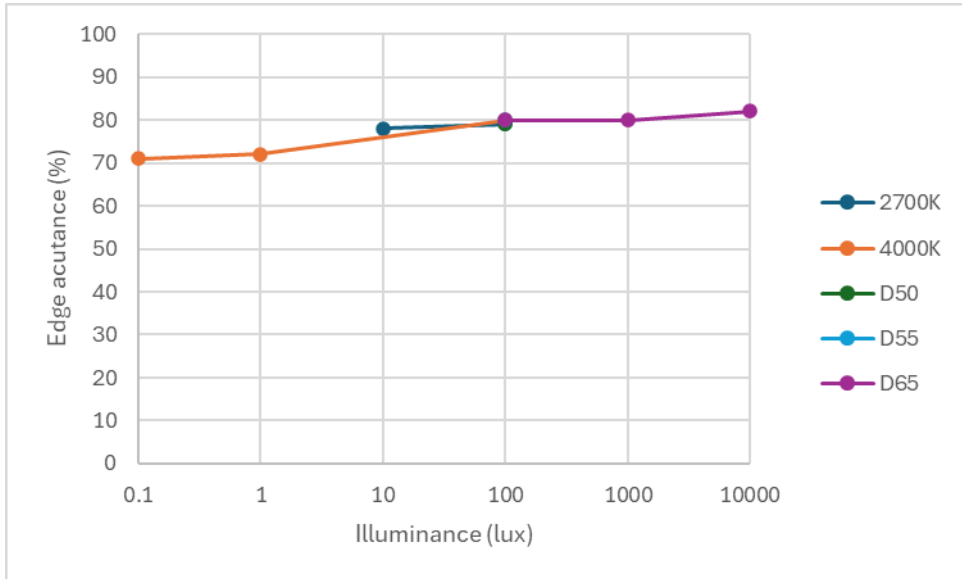
• Texture Acutance



	(lux)	2700K	4000K	D50	D55	D65
Texture acutance (%)	0.1		59			
	1		72			
	10	72				
	100	80	81	81	80	81
	1000					80
	10000					84

- Viewing conditions:
 - Distance: 600mm
 - Pixel pitch: 0.254mm

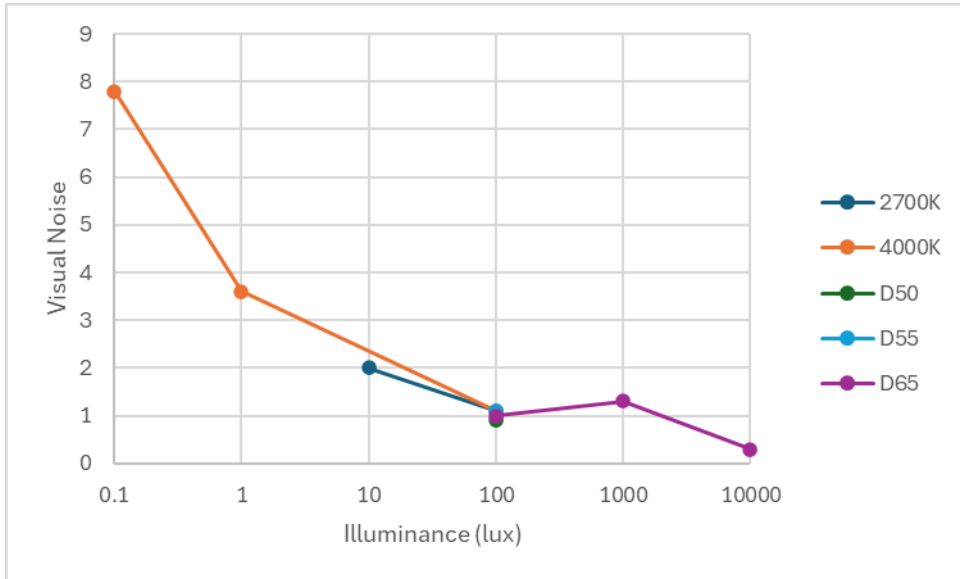
• Edge Acutance



	(lux)	2700K	4000K	D50	D55	D65
Edge acutance (%)	0.1		71			
	1		72			
	10	78				
	100	79	80	79	80	80
	1000					80
	10000					82

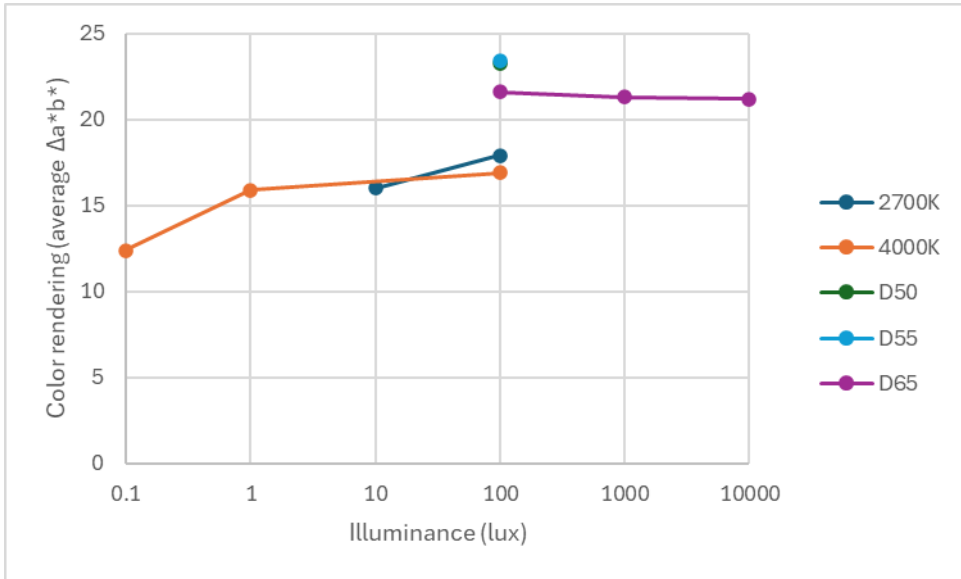
- Viewing conditions:
 - Distance: 600mm
 - Pixel pitch: 0.254mm

• Visual Noise



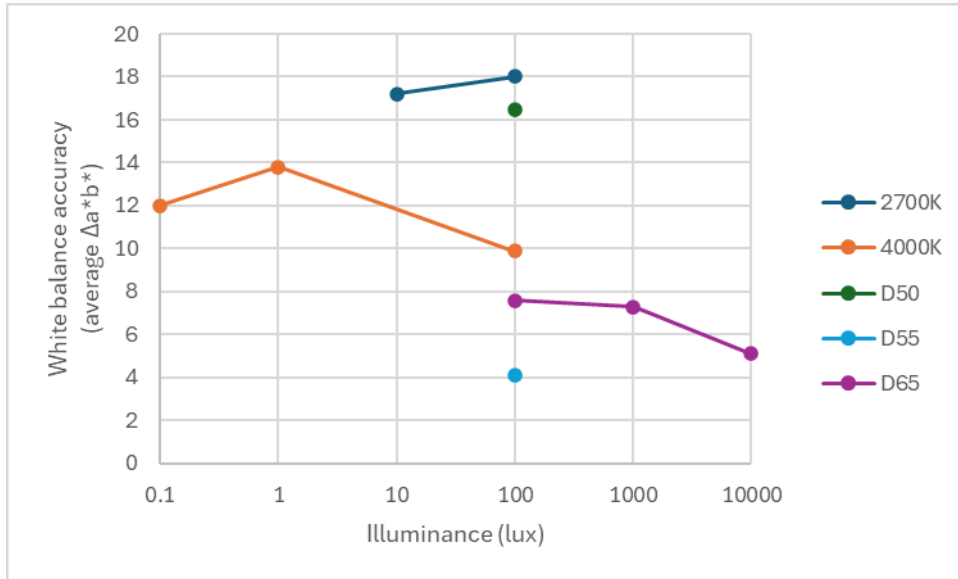
	(lux)	2700K	4000K	D50	D55	D65
Visual Noise	0.1		7.8			
	1		3.6			
	10	2				
	100	1.1	1.1	0.9	1.1	1
	1000					1.3
	10000					0.3

• **Color Rendering**



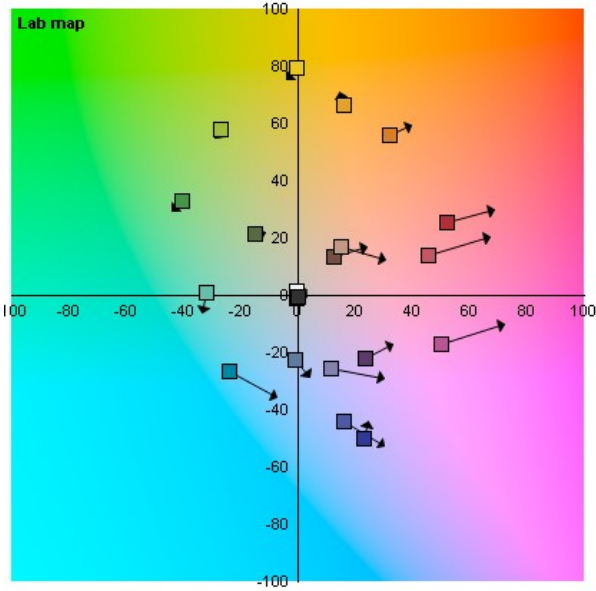
	(lux)	2700K	4000K	D50	D55	D65
Color rendering (average Δa^*b^*)	0.1		12.4			
	1		15.9			
	10	16				
	100	17.9	16.9	23.3	23.4	21.6
	1000					21.3
	10000					21.2

• White balance accuracy

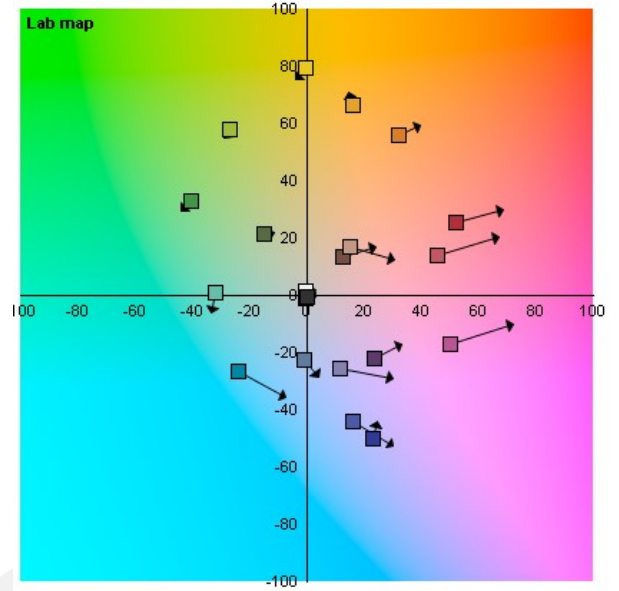


	(lux)	2700K	4000K	D50	D55	D65
White balance accuracy (average Δa^*b^*)	0.1		12			
	1		13.8			
	10	17.2				
	100	18	9.9	16.5	4.1	7.6
	1000					7.3
	10000					5.1

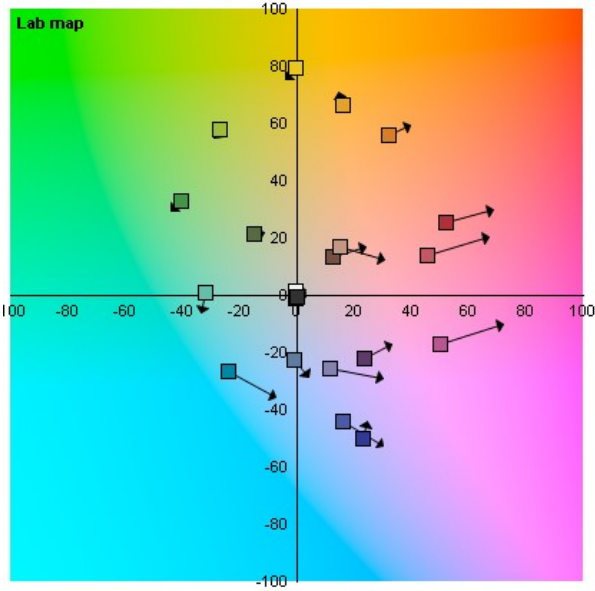
Illuminant: 2700K 10 lux



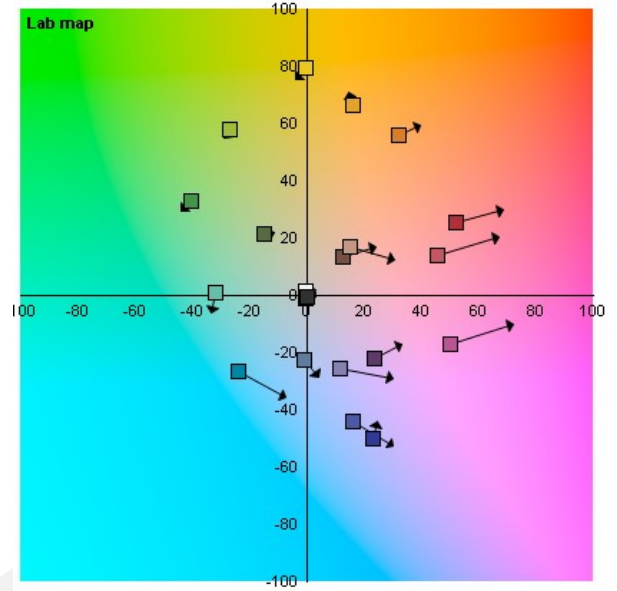
Illuminant: 2700K 100 lux



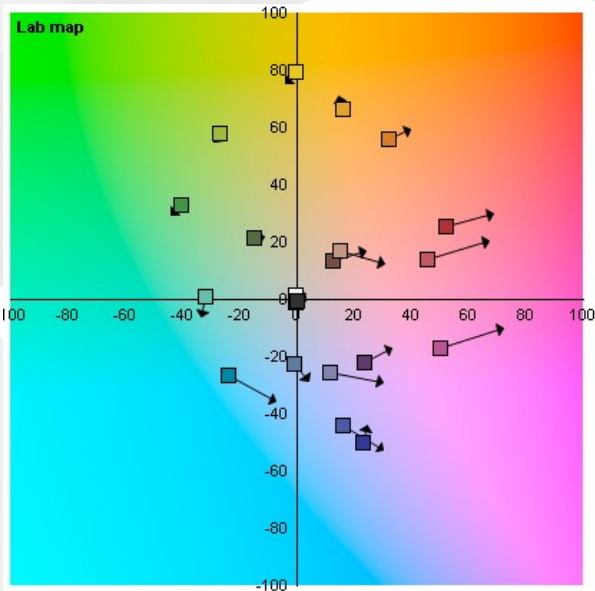
Illuminant: 4000K 0.1 lux



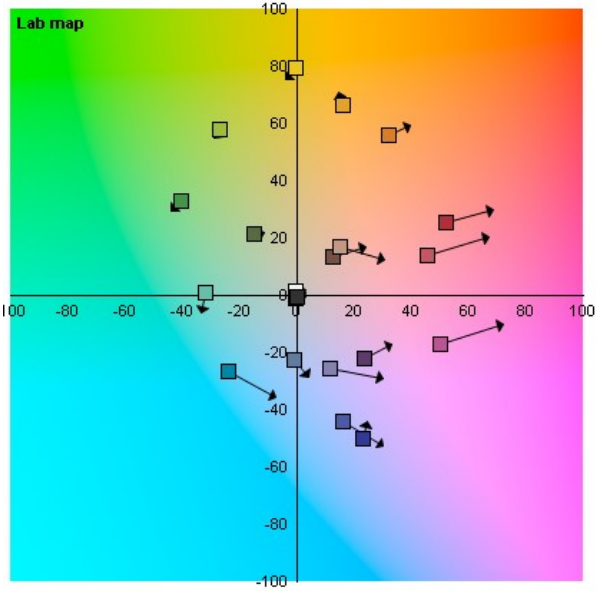
Illuminant: 4000K 1 lux



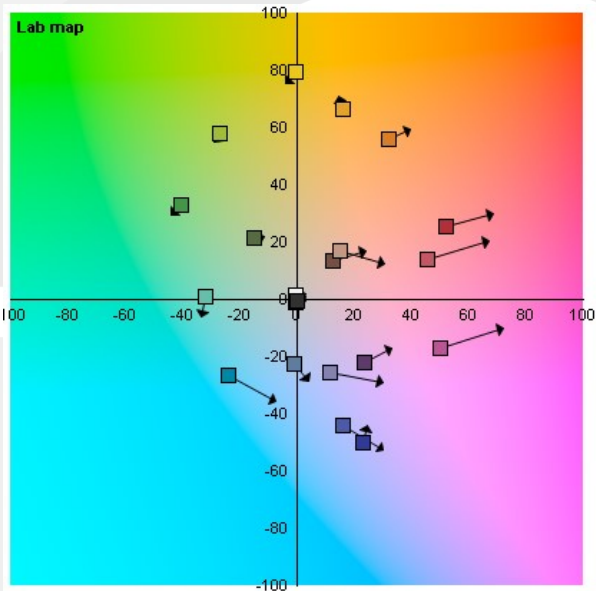
Illuminant: 4000K 100 lux



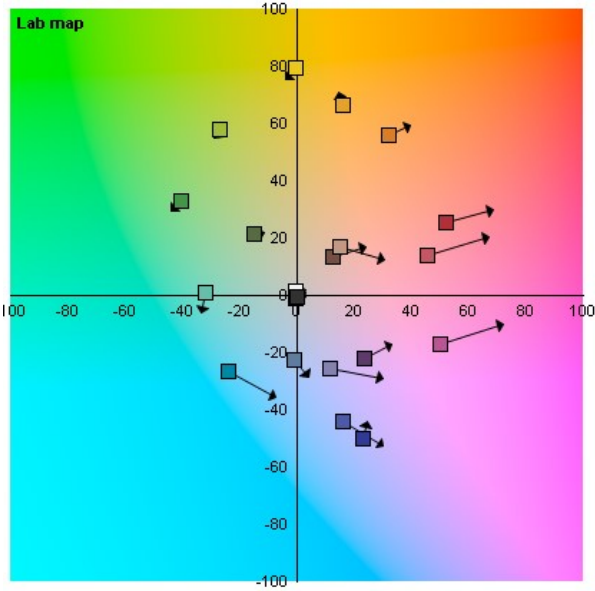
Illuminant: D50 100 lux



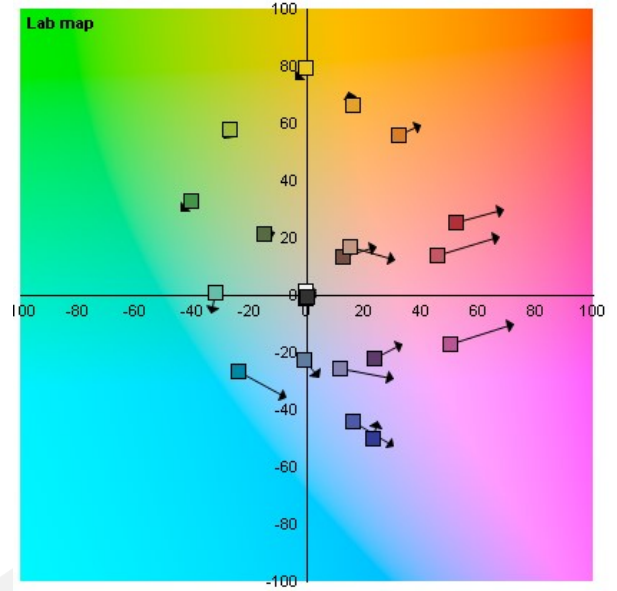
Illuminant: D55 100 lux



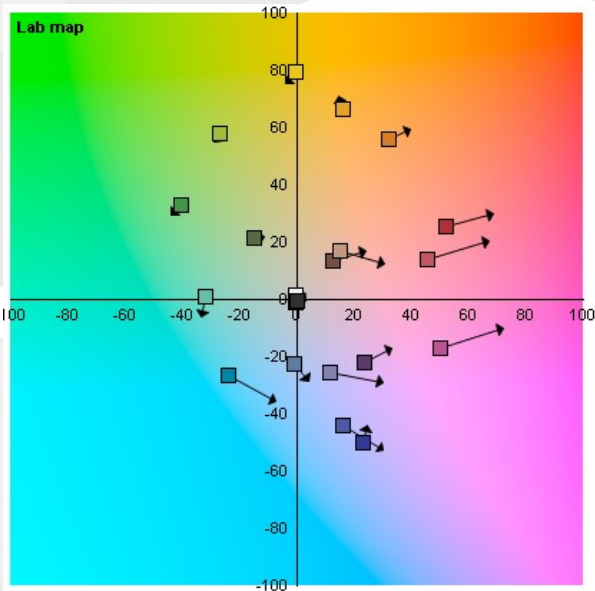
Illuminant: D65 100 lux



Illuminant: D65 1000 lux



Illuminant: D65 10000 lux





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