Instrument Systems
KONICA MINOLTA Group

Improving takt time and accuracy by advanced LumiTop calibrations

The increasing variety of light sources and the emergence of new display technologies are posing new challenges for 2D imaging colorimeters and their color calibrations. In particular, deviations in spectral characteristics between calibration sources and devices under test (DUTs) can significantly impact measurement accuracy, requiring more flexible and application-specific calibration approaches.

The Instrument Systems LumiTop imaging colorimeter series addresses these challenges by combining high-resolution camera with a CAS 140D spectroradiometer as a traceable reference. This unique approach enables highly accurate two-dimensional measurements of luminance and color. The standard factory color calibration of the LumiTop series is optimized for conventional LCD or OLED flat panel displays, ensuring reliable and repeatable results for most current display technologies.

To meet the requirements of advanced and emerging display types, Instrument Systems has developed enhanced color calibration concepts for the LumiTop series: **LiveCal** and **MyCal**. These advanced calibrations allow the color calibration to be tailored to specific sample types and applications, thereby maximizing measurement accuracy, yield and throughput in demanding manufacturing application. As a general principle, the closer the spectral characteristics of the calibration source match those of the DUT, the more precise the resulting color measurements become – an advantage that LiveCal and MyCal are specifically designed to deliver.

APPLICATION
NOTE

\\ 1. LUMITOP COLOR CALIBRATION CHAIN

The LumiTop measurement principle is based on combining an RGB camera image with a simultaneously or sequentially measured high accuracy CAS 140D reference spectrometer. The RGB camera image is converted into the XYZ tristimulus values using the factory camera Color Calibration (CC). In order to improve the color and luminance accuracy for each individual measurement, reference tristimulus values are obtained from a real-time CAS spectral measurement and used for fine-correcting the camera color calibration.

This fine-correction effectively corrects for the potential mismatch between factory calibration source and DUT. For conventional LCD or OLED displays or any kind of light sources with broad spectral emission the combination of factory color calibration with real-time spectral fine correction provides highly accurate results. To enhance the color accuracy for samples with larger spectral variations or narrow-linewidth emitters such as microLEDs, Instrument Systems has developed advanced color calibrations named **LiveCal** and **MyCal**.

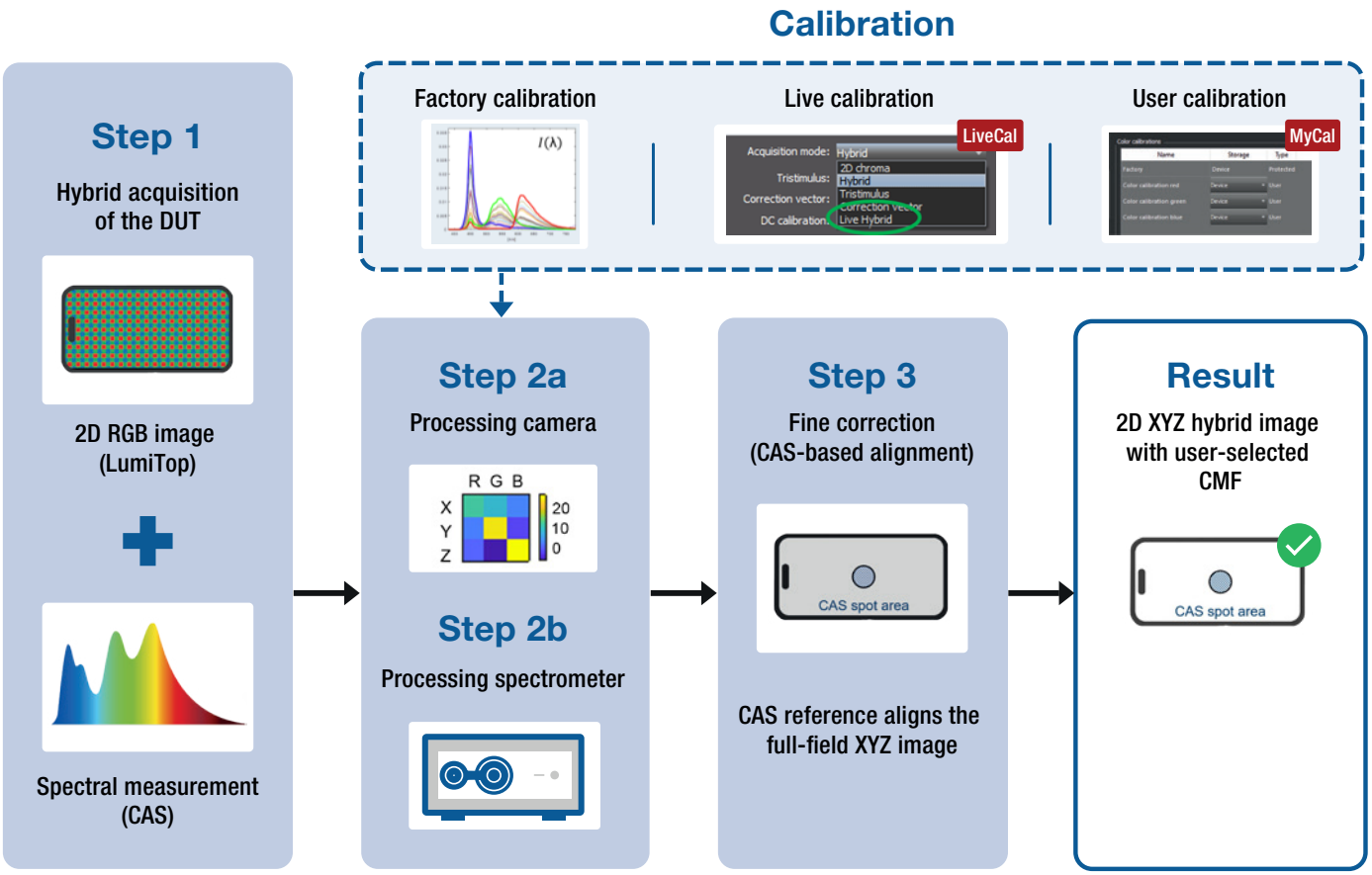

Fig. 1: Processing workflow of the LumiTop. Either factory calibration, LiveCal or MyCal can be used for the RGB-to-XYZ color conversion.

They offer the possibility to customize the camera color calibration for the measured sample type or even individually measured samples. This is achieved by a special calibration procedure which is performed within the calibration process in order to create camera-specific Enhanced Calibration Data (ECD). With this ECD, an optimized color calibration tailored to the customer sample can be created based on the spectral CASmeasurement of the DUT and used instead of the factory color calibration. This leads to highly accurate color measurements, even for advanced and demanding display technologies.

But also for conventional LCD or OLED displays there are several use cases where MyCal offers better results compared to the standard factory calibration. The most prominent use cases will be described in the following chapters.

\\ 2. LIVECAL: OPTIMIZED COLOR CALIBRATION IN REAL TIME

LiveCal creates an optimized color calibration for the measured sample in real-time. The workflow is very simple: If the acquisition mode **Live Hybrid** is chosen instead of Hybrid, the measured CAS spectrum is used for calculating a new LumiTop camera calibration for every measurement, based on the spectral characteristics of the sample. Since the color calibration is specifically tailored to the measured DUT, LiveCal provides the best color accuracy for every measurement, as long as the measured CAS 140D spectrum is representative for the sample.

An example measurements of a monochromatic RGB microLED display can be seen in figure 2. The Mean Average Error (MAE) measured with the LiveCal feature (Live Hybrid acquisition mode) is significantly smaller compared to the standard Hybrid acquisition mode using the factory calibration. The spectral shift over the Field of View (FOV) was less then 1 nm for this DUT. For samples with large spectral shift, the improvement due to LiveCal will be even more significant. Also, in case of frequently changing spectral characteristics of the DUT, LiveCal will be beneficial compared to standard calibrations.

Acquisition mode	Red		Green		Blue	
	x	y	x	y	x	y
Hybrid	0.17×10^{-3}	0.20×10^{-3}	0.92×10^{-3}	1.7×10^{-3}	0.38×10^{-3}	0.57×10^{-3}
Live Hybrid	0.08×10^{-3}	0.046×10^{-3}	0.70×10^{-3}	0.57×10^{-3}	0.14×10^{-3}	0.22×10^{-3}

Fig. 2: Mean Absolute Errors (MAE) of the color coordinates x,y measured on a monochrome RGB microLED display with Hybrid and Live Hybrid acquisition mode.

\\ 3. MYCAL: USER-CREATED CUSTOMIZED CALIBRATIONS

MyCal offers the possibility to create and save a custom color calibration. It can be created before the measurement from a previous LiveCal measurement or by customer spectral data from one or multiple spectra. The created calibration can be easily saved to the LumiTop and used multiple times even in camera-only mode without the spectroradiometer.

MyCal is especially beneficial for production environment, where static color calibration is preferred over constantly adapting LiveCal calibration, but optimized color accuracy is still desired. Unlike LiveCal, MyCal custom color calibration can be created using more than one spectrum, which for example allows creating a color calibration from a representative batch of DUTs. MyCal is also suitable for applications where a real-time spectral measurement with the spectroradiometer is not possible. Next, some example use-cases for MyCal are introduced.

3.1 Reducing the takt time with MyCal

For our sequentially operating LumiTop devices such as LumiTop X20, X30 and X150, MyCal enables reducing the takt time tremendously while maintaining high color accuracy. Tailored color calibration can be created beforehand from a CAS 140D spectrum or LiveCal measurement and applied to camera-only measurements in production lines.

Figure 3 shows measurement time results from a commercial OLED phone display for the different test patterns white, red, green, blue and two low luminance grey levels. By performing camera-only measurements with previously taken MyCal calibrations, the measurement time can be reduced up to 50% for sequentially operating LumiTop X devices. At the same time the color accuracy for x,y remains at values of around 1 color point (cp) while the luminance accuracy stays below 1 %. These deviations get larger for very low luminance measurements such as 0.002 cd/m² as shown in figure 3. However, even at these extreme conditions MyCal enables accurate color and luminance measurements at measurement times of 10 seconds or less.

	DUT luminance	Measurement time		Delta to CAS reference (camera only with MyCal)		
	L [cd/m²]	Hybrid mode [s]	Camera mode (MyCal) [s]	Δx [cp]	Δy [cp]	ΔL [%]
White	357	1.54	0.69	-1.1	0.9	-0.1
Red	135	1.38	0.69	1.1	-1.1	0.4
Green	354	1.41	0.69	-0.5	1.0	0.5
Blue	28	1.71	0.89	1.8	-1.5	0.9
Grey 32	0.021	21.0	10.5	0.4	0.1	-0.8
Grey 16	0.002	20.8	10.5	0.9	-2.7	6.8

Fig. 3: Measurement time and accuracy of a camera-only measurement with MyCal calibrations for the individual DUT patterns white, red, green and blue.

3.2 Low luminance measurements with MyCal

At very low luminance conditions, the signal levels of the CAS reference can be too low to achieve accurate hybrid measurements. In this case, MyCal can be used to achieve high color accuracy. A color calibration can be created from a reference CAS 140D or LiveCal measurement and used afterwards for performing low luminance measurements in camera-only mode.

The figures 4a and 4b show example measurements of a commercial OLED phone display at two different low luminance levels of 0.01 cd/m² and very low luminance of 0.001 cd/m². Shown are the results of a camera-only (2D Chroma) measurement with MyCal calibration and the standard hybrid measurement based on the factory calibration. A CAS 140D spectrum was measured for reference on each of the 9 positions shown in figure 5. As can be seen in the figures, at certain low luminance conditions a camera-only measurement based on MyCal calibration will lead to similar or improved color accuracy compared to the standard hybrid measurements. This is accompanied by significantly shorter measurement times when measuring the LumiTop X series sequentially, as described in the previous chapter.

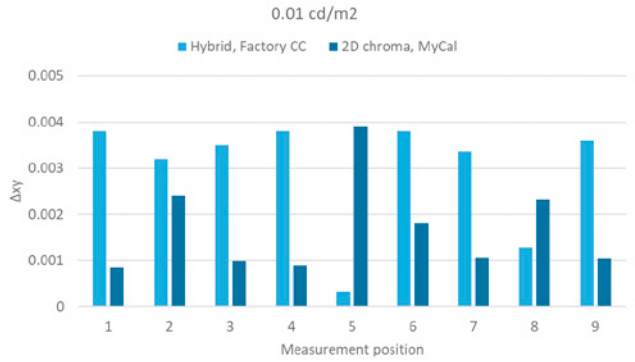

Fig. 4a: Color difference relative to CAS reference for 9 spots measured at 0.01 cd/m². The color errors with MyCal are smaller.

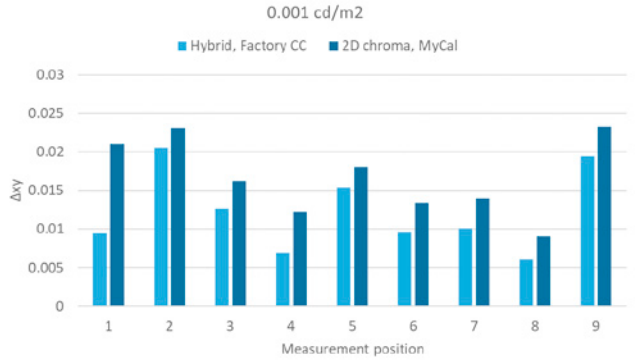

Fig. 4b: Color difference relative to CAS reference for 9 spots measured at very low luminance of 0.001 cd/m². Hybrid and MyCal deliver similarly good results.

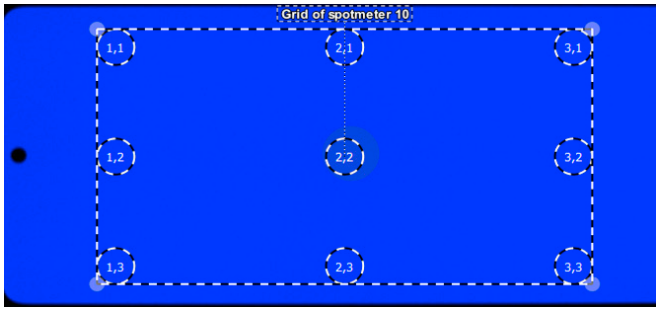

Fig. 5: OLED DUT with 9 spots for color and luminance evaluation.

\\ 4. CONCLUSIONS

Our advanced calibration methods LiveCal and MyCal were especially designed for use cases which differ from common flat panel testing. For new display technologies such as microLED displays with large spectral spread, LiveCal can help to improve color accuracy results tremendously.

In case of LCD or OLED flat panel testing under special conditions such as short takt times or very low luminance measurements, MyCal will provide the best results. In particular, at luminance levels below 0.1 cd/m², MyCal delivers better or at least comparable color accuracy compared to hybrid measurements.

Recommended example use cases for each color calibration type are summarized in the table below.

Color calibration modes

01

Factory color calibration

- LCD or OLED flat panel testing at standard brightness conditions
- Spectrally uniform samples

02 Adaptive

LiveCal

- Spectral shift between samples is high
- Frequently changing sample types
- The highest achievable color accuracy is required

03 Custom

MyCal

- Reducing the takt time with LumiTop X series
- Low luminance conditions below 0.1 cd/m²
- Calibration created from multiple reference sample spectra

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