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Subpixel measurement for OLED and µ-LED displays in production lines

The desire for ever higher display resolutions drives display innovations. Especially µ-LEDs are considered to be the future enabling technology for very high resolutions.
For quality control and calibration of high-resolution displays (OLED or µ-LED) in production lines, it is crucial to measure the optical properties of each individual subpixel under the constraints of production tact times. Thus, luminance and color (X, Y, Z) images with extraordinary high resolutions are mandatory for reasonably accurate measurements of luminance and color on a subpixel level. Current state-of-the art solutions either employ several coupled devices or make use of positioning stages to capture multiple images combined with image stitching software in order to reach the necessary resolutions. Such solutions are often very expensive and time-consuming.
Here we introduce the new ultra high resolution LumiTop X150, a single-device solution for all display testing tasks in production lines including subpixel measurement of high-resolution displays.

APPLICATION
NOTE

\\ 1. INTRODUCTION

More pixels! This is a major trend in the display industry. While one can argue about the benefit of 8K or even higher resolution TVs, more (i.e. smaller) pixels with higher fill factors are needed for near-the-eye applications as, e.g., VR goggles. With displays so close to the observer's eye, screen-door effects and pixel non-uniformities are easily visible and disturbing for the consumer. µ-LEDs are believed to be an enabling technology for very high resolutions with pixel sizes as small as 10 µm and equally small pixel pitches. In general, µ-LEDs have the potential to be a disruptive display technology if the mass production issues can be solved. Just like OLED displays, µ-LEDs are an emissive display technology, i.e. each single subpixel is a light source itself. Luminance and color variations between the pixels are likely and strongly influence the visual quality of the display. Consequently, quality control and subsequent calibration of the displays are mandatory, not only in the laboratory, but especially in production lines. The race for very high resolutions, driving display innovation, not only challenges the display manufacturers and their supply chain, but also the test equipment suppliers.

\\ 2. NEW CHALLENGES FOR OPTICAL TESTING IN PRODUCTION LINES

While optical quality control of displays in production lines is important, yield and throughput are crucial for cost-effectiveness and profitability and thus very often dictate the scope of test procedures. Essentially, this means that the available time for optical performance testing is strictly limited. This is a very well-known challenge for all equipment suppliers. With the introduction of new and improved display technologies (in terms of color gamut, dynamic range, etc.) like, e.g., OLEDs and in future µ-LEDs, the challenges become more severe, because the requirements for test systems increase in parallel with the quality of the displays. At the same time, less mature technologies may also demand a wider or different scope of testing. As stated above, OLEDs and µ-LED displays are both emissive display technologies, which means that each sub-pixel is a light source itself and variations in luminance and / or color are very likely. Detecting defect pixels and subpixel measurement with subsequent display calibration / correction is important to increase the yield especially for new technologies. This presents a great challenge for equipment manufacturers, because luminance and color of millions of tiny subpixels of OLED or µ-LED displays (with pixels sizes as small as 10 µm and below) have to be evaluated under the constraints of typical production line tact times.

\\ 3. INSTRUMENT SYSTEMS' SOLUTION: LUMITOP X150

Instrument Systems offers a wide range of display testing systems for lab as well as for production testing. The LumiTop family is very well-known for its benefit of combining very high measurement accuracy and speed. Along with our deep metrology know-how guaranteeing traceability and instrument-to-instrument reproducibility, world-wide technical support and service capabilities as well as powerful but intuitive software for easy production integration, our measurement systems are the superior choice for optical quality control of displays in production lines. Based on this successful concept, we developed a new LumiTop model that meets the challenging requirements of high resolution display testing, in laboratory applications as well as in production test environments.

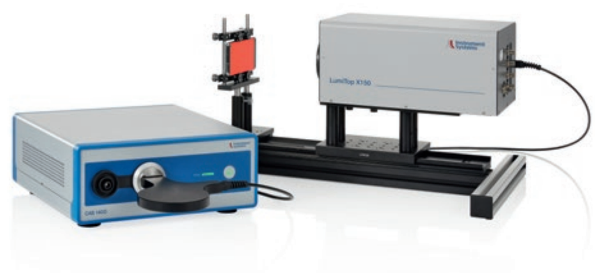

Fig 1: Ultra high resolution LumiTop X150 including CAS 140D spectroradiometer in a laboratory setup.

The LumiTop X150 combines a 150 megapixel camera with the high-end spectroradiometer CAS 140D. The sophisticated concept of a camera- spectroradiometer combination is the heart of all LumiTop devices. This design allows for using the very accurate spectral measurement of the CAS 140D as live reference for the camera measurement. This guarantees highest accuracy over the complete field of view of the camera. In other words, it combines the advantages of both device types, i.e. the accuracy of spectroradiometric spot-measurement, which is especially important for narrow-banded light sources like OLEDs or µ-LEDs, and the capability of capturing a whole display with one single measurement. In addition, a photodiode measures time-dependent properties like flicker or luminance modulations. Further, the optical design of the instrument was optimized with respect to its sensitivity achieving an unprecedented low luminance performance.

In the past, camera resolutions up to 12 megapixel were (and still are) sufficient for most display test applications. However, single pixel or sub-pixel evaluations require much higher camera resolutions. Preliminary experiments show, that sampling rates of at least 4:1 are needed for accurate color measurements. Therefore, this next generation device is equipped with a 150 megapixel sensor, a resolution that — to the knowledge of the author — no other luminance or color measurement device on the market can offer. Pushing the boundaries regarding resolution, the LumiTop comes with an internal shifter to even increase the resolution up to 600 megapixels. The instrument also features a motorized focus lens that can be used to automatically adapt to different focus levels (of, e.g., different color test patterns or to measure defocused). However, the hardware is only part of the challenge. Sophisticated algorithms have been developed to generate pixel intensity and pixel color maps for defect pixel detection or display calibration. Moreover, the device calibration is optimized to the specific set of spectra of the respective sample.

\\ 4. BENEFIT: SINGLE DEVICE SOLUTION FOR PRODUCTION TESTING

The ultra high resolution LumiTop X150 is the answer to all display measurement tasks in production lines. With unprecedented accuracy and high measurement speed it measures the spectrum of DUTs, captures highly accurate images for color and luminance uniformity (Mura) or defect evaluations, it allows for gamma curve corrections, flicker and luminance modulation measurements and many more. Uniquely, it also provides a solution for all tasks where very high resolutions are needed like, e.g., display calibration (sometimes referred to as “demura”). There is no need for any other type of instrument, no need to couple several devices of the same type or move the instrument and thus no need for image stitching software (that often cannot correct for the distortions). All measurement tasks can be performed in a single test station. This saves the customer room, time (i.e. money) and investment costs.

On the next pages examples are given for:
- Subpixel analysis – absolute measurements
- Subpixel analysis — relative measurements
- Uniformity measurement

Covering all relevant optical production test tasks, the LumiTop X150 provides an extremely cost-effective, comprehensive high-end test solution for quality control and calibration of displays in production environments. Moreover, due to its very high accuracy, it can as well be used as reference instrument and for in-depth evaluations in the laboratory.

Example 1:
Subpixel analysis – absolute measurements

Figure 2 shows different zoom levels of images captured from an OLED mobile phone displaying the BLUE pattern (2x2 images employing the internal pixel shifter). Every single blue OLED pixel of the whole display can be resolved with sufficient resolution for accurate color and luminance evaluation.

Based on such data, a sophisticated algorithm is able to provide a pixel map with accurate color and luminance information of every subpixel. This information can then be used for further analysis or display calibration (often called Demura in the case of OLED displays).

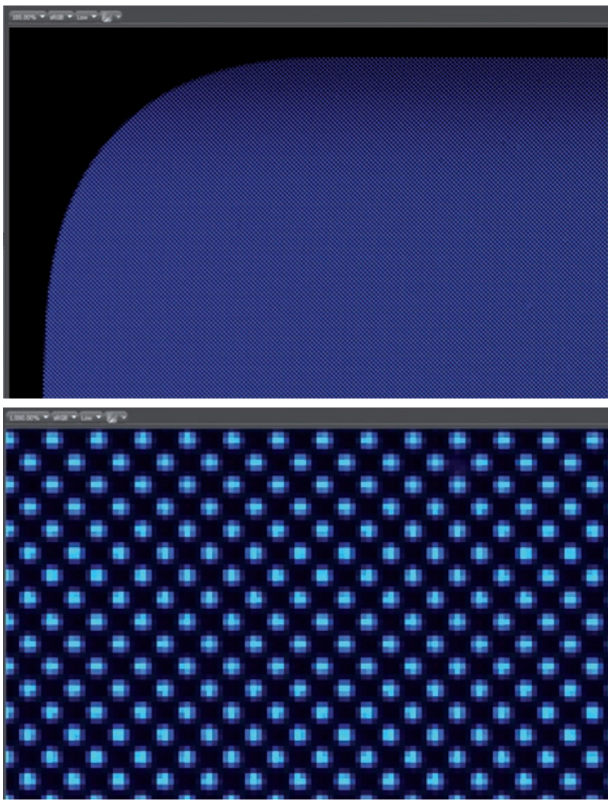

Fig 2: Blue pattern displayed by state-of-the art OLED display measured with LumiTop X150 (2x2 sampling), with different zoom levels.

Figure 3 shows the luminance distribution of the same display as in figure 2 but with increased resolution of 600 megapixels (4x4 images) in false color representation. The number of "shifted" measurements can be adapted as to the resolution needed for the specific device under test. In the example shown below two line profiles are drawn (black / white lines and dotted line in top frame) to evaluate the lateral distribution of luminance. Obviously, very detailed analyses of every blue subpixel are possible. The bottom left diagram shows luminance distribution along the x-axis for one single pixel, the bottom right profile covers in total 15 blue subpixel for comparison. Of course, further analysis tools like spotmeter for averaged luminance or color information, histograms, uniformity calculations etc. are available in the LumiSuite software.

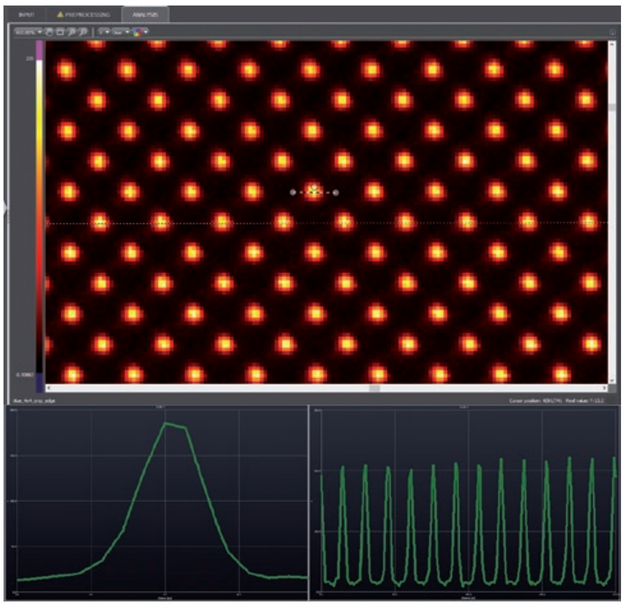

Fig 3: Luminance distribution of OLED mobile phone displaying blue pattern in pseudo color representation (top frame). Bottom left profile, corresponding to Black-and-white dashed line in top frame, shows luminance distribution along the x-axis of a single blue OLED subpixel. Bottom right profile, corresponding to dotted line in top frame, shows horizontal luminance distribution along 15 blue subpixels.

Example 2:
Subpixel analysis — relative measurements

Some analyses — like pixel defect detection or mura measurements — do not need absolute measurements of color and luminance. For this purpose, Instrument Systems has developed an additional fast algorithm that enables the analysis of whole displays with one single measurement of the LumiTop X150. This algorithm generates a pixel intensity map as shown below (top frame Fig. 4). The user can then set appropriate pass / fail criteria in the pixel defect detection tool to evaluate his display. The bottom frames of Figure 4 are zoomed cutouts of the top frame before (left) and after (right) the tool was applied. The red crosses in the bottom right frame mark the defect pixels according to the fail criteria of 30% luminance deviation compared to the neighboring pixels.

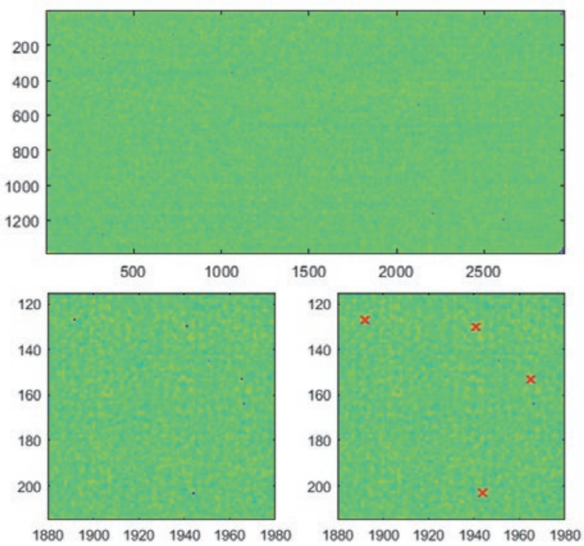

Fig 4: Pixel intensity map of an OLED mobile phone (top) and zoomed cutouts before and after the pixel defect detection tool was applied. Red crosses indicate defect pixels according to the applied fail criteria (> 30% deviation to median filter of 7 neighboring pixels).

Example 3:
Uniformity measurement

The pixel maps can obviously be used as basis for many different evaluations, but subpixel measurement may be a little overdone for some tests. In many cases, where data on subpixel level are not needed, increasing the measurement speed by data reduction (i.e. shorter transfer times) is more important. Examples are uniformity and large scale, i.e. low frequency mura measurements, gamma curve or white point corrections and so on. In this case, the very high resolutions are not needed. Some applications, like the “Uniformity measurement standard for displays” of the German car industry, even specify to measure defocused. The LumiTop X150 features a lens with motorized focus so that the user can easily switch between focused or defocused measurement.

Figure 5 shows the luminance uniformity of an OLED tablet displaying WHITE in pseudo color representation. In addition, a line profile was set across the diagonal (bottom left to top right corner) of the display. The corresponding diagram in the top right corner of Figure 5 illustrates the significant luminance drop along this line. In addition, a grid of nine spots was placed on the image in order to receive information about max, min and average luminance and color within the spots and / or about the uniformity between the spots. The results are shown in a table below the captured image (only one line is visible in the figure).

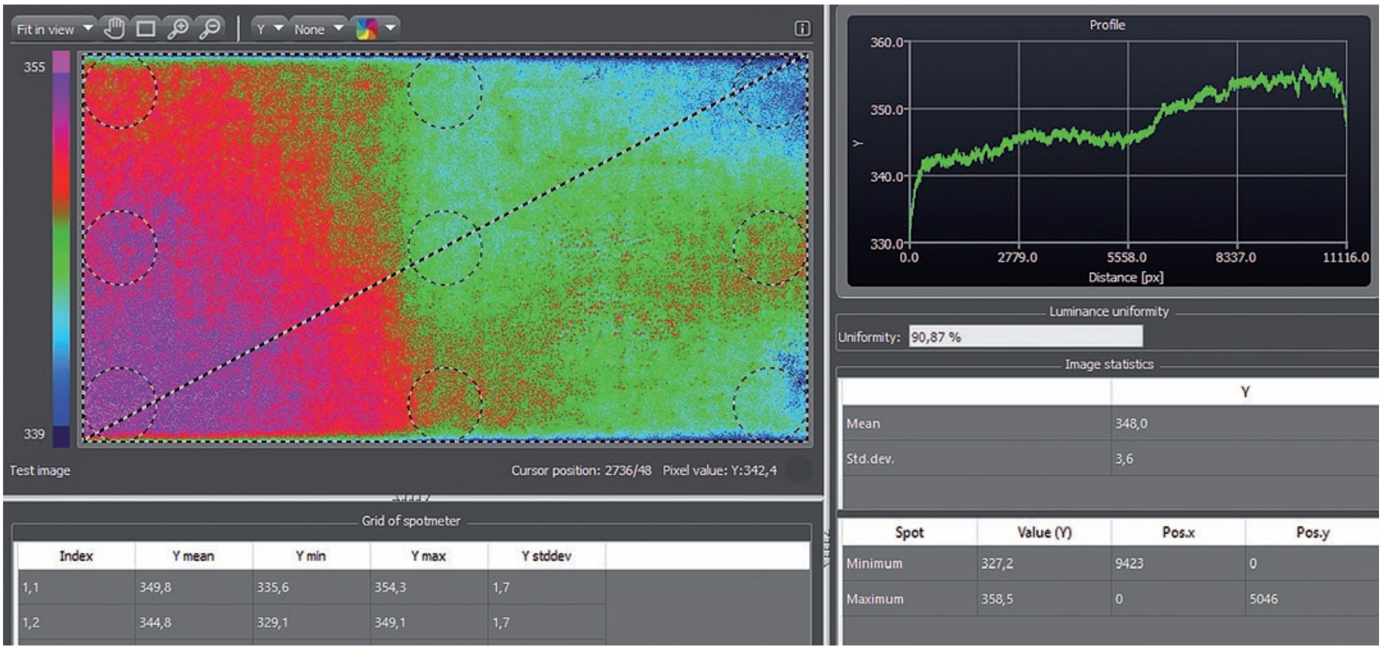

Fig 5: Uniformity analysis of an OLED tablet displaying Green in pseudo color representation. Luminance values vary between 327 and 359 cd/m². Diagonal line represents vertically averaged (20 pixels) luminance profile from bottom left to top right corner of the display. The line profile, uniformity results and image statistics are shown on the right of the image. Grid of nine spot meters was placed in top frame for min, max, average luminance and color within the spots and uniformity across the display. Results are noted in the bottom table (only two lines shown on the image).

\\ 5. BENEFIT: INSTRUMENT SYSTEMS AS STRONG PARTNER FOR YOUR TEST APPLICATIONS

With Instrument Systems as their partner, customers not only benefit from superior hardware and software solutions engineered in Germany. Instrument Systems is also a highly competent partner for all optical display tests in production lines. With our in-depth metrology know-how, we guarantee calibrations traceable to national institutes, absolute measurement accuracy with defined error-budgets and high instrument-to-instrument reproducibility. We have international service facilities and an experienced customer support management team for quick customer support and service. Moreover, we have dedicated structures for application support and customization in order to provide the perfect solution to the customers' individual challenges.

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