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QUALITY ASSURANCE WITH CALIBRATION TOOLS FOR MOBILE SMART PHOTONIC DIMENSIONAL, COLOR AND SPECTRAL MEASUREMENT SYSTEMS

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ABSTRACT & Introduction

Mobile smart photonic measurement systems are convenient, reliable and affordable. Microsoft have been released their Windows 8 operating system in 2012. Windows 8 opens new possibilities for the development of innovative measurement systems. Touchscreens on smartpads and standardized USB-Interfaces ease the application of consumerized smartpads also for commercial tasks. Innovative mobile photonic measurement systems are the combination of miniaturized dimensional, color and spectral sensor modules with smartphones and smartpads under Microsoft Windows 8 operating systems and commercial available software packages for industrial and non-industrial applications. One of the big challenges is their mobile and task specific calibration in field.

Smartphones and smartpads are becoming significant game changers not in consumerized applications only. Aim of the paper is to show selected examples for the application of smartphones and smartpads directly in field measurements. Significant influence on the accuracy of field measurements have available tools for mobile calibrations. Selected mobile calibration tools for mobile smart photonic dimensional, color and spectral measurement systems will be represented and explained.

Index Terms **–** smart, mobile, calibration, dimensional, color and spectral

1. Mobile smart photonic measurement systems

Mobile smart photonic systems are a combination of smartphones, smartpads and/or smart wearables (smartcomps) with additional task specific hardware apps (hwapps) and unified software apps (swapps). Mobile smart photonic measurement systems are categorized in dimensional (Figure 1) [1], color (Figure 2) [1] and spectral (Figure 3) [1] measurement systems.

Figure 1: Mobile smart photonic dimensional measurement systems

Figure 2: Mobile smart photonic color measurement systems

Figure 3: Mobile smart photonic spectral measurement systems

Typical photonic **dimensional** measurement hardware apps are digital miniature cameras and microscopes with standardized CMOS sensors, USB interfaces and flexible S-Mount lenses (Figure 4) [2].

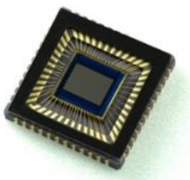
<table>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>CMOS sensors</td><td>Hardware modules</td><td>USB interfaces</td><td>S-Mount lenses</td></tr>
<tr><td></td><td colspan="3">Sensor: CMOS RGB Bayer Matrix, 5 MP 2592x1944 pixels, 1/2.5
Digital interface and power requirements: 5V USB 2.0, typ. 0.6W
Dimensions and Weight WxHxD: 15 x 15 x 8 mm, 5 g</td></tr>
</table>

Figure 4: Mobile smart photonic dimensional measurement hardware apps

Typical photonic **color** measurement hardware apps are digital miniature colorimeters or photometers with standardized True Color sensors, USB interfaces and SMA-Connectors (Figure 5) [3].

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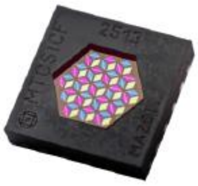
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>True Color sensors</td><td>Hardware modules</td><td>USB interfaces</td><td>SMA-Connectors</td></tr>
<tr><td></td><td colspan="3">Sensor: Tri-stimulus value function, digital resolution 16 bit
Digital interface and power requirements: 5V USB 2.0
Dimensions and Weight WxHxD: 89 x 32 x 27 mm, 20 g</td></tr>
</table>

Figure 5: Mobile smart photonic color measurement hardware apps

Typical photonic **spectral** measurement hardware apps are digital miniature spectrometers preferably with standardized linear CCD sensors, USB interfaces and SMA-Connectors (Figure 6) [4].

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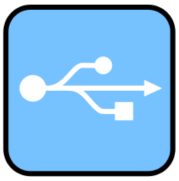
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Linear CCD sensors</td><td>Hardware modules</td><td>USB interfaces</td><td>SMA-Connectors</td></tr>
<tr><td></td><td colspan="3">Sensor: 2500 pixel linear CCD, 360 - 740 nm, 1.2 nm FWHM
Digital interface and power requirements: 5V USB 2.0, 150 mA
Dimensions and Weight WxHxD: 85.7 × 22.0 × 10.0 mm, 10 g</td></tr>
</table>

Figure 6: Mobile smart photonic spectral measurement hardware apps

2. Mobile smart photonic measurement systems applications

The mobile application of photonic hardware apps and software apps with smartpads in field opens so far untapped new markets for photonic measurements (Figure 7) [1].

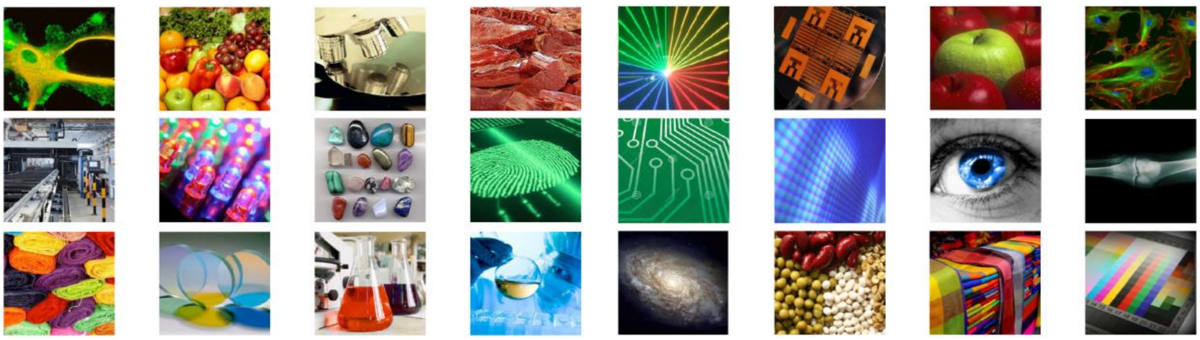


Figure 7: Items for mobile smart photonic measurement systems applications

Due to changing environmental conditions the in field measurements might be more complex than laboratory measurements. Nevertheless the resolutions, accuracies and reproducibilities of in field and laboratory measurements should be comparable. Main problem is the task specific calibration of in field measurement systems.

3. Example calibration procedure of photonic color measurement systems

A common and easy method to calibrate tristimulus colorimeters for in-field measurements is the global correction via a target-based correction matrix. This method is based on a general comparison of existing reference values (or measured values of a spectrometer) with the actual values of a tristimulus colorimeter sensor. The difference between the reference values and actual values will be used for the calculation of a correction matrix. The correction matrix is fundamental to guarantee the high accuracy of the tristimulus colorimeters.

The measurements of the XYZ color values with a spectrometer and a tristimulus XYZ sensor are parallelized. The relationship between the reference measurements with spectrometer values (T) and the tristimulus XYZ sensor values of the colorimeter ($\underline{S}$) shows the matrix equation (1).

$$\underline{T} = \underline{K} \cdot \underline{S} \tag{1}$$

After the transposition of equation (1) the correction matrix ($\underline{K}$) can be calculated by equation (2).

$$\underline{K} = \left(\underline{T} \cdot \underline{S}^T\right) \cdot \left(\underline{S} \cdot \underline{S}^T\right)^{-1} \tag{2}$$

For a compensated, balanced and calibrated tristimulus colorimeter measurement the following steps have to be accomplished:

Calibration Step 1: Offset compensation
To consider potential errors by added electronic components the sensor must be darkened and a measurement performed. The amplification levels of color and dark measurements are the same. The offset must be subtracted from the normal measurement signal of the sensor to enable the calculation of the correction matrix.

Calibration Step 2: White balancing
White balance temperature and aging related spectral shifts of the optical system (sensor, LED, optics) will be compensated by the following methods:

- either measuring an aging stable white standard,
- or comparing the light sensor with a second sensor of the same type.

Calibration Step 3: Measurement with calibration references
Investigation of the tristimulus colorimeter and the reference spectrometer alternating with the linear independent calibration references.

Calibration Step 4: Calculation of the correction matrix
Calculation and application of the target-based correction matrix for the measurement task.

After the offset compensation, white balancing and calibration the tristimulus colorimeter can achieve similarly accurate readings in the same color measurement applications as standard spectrometer.

The measurements with the tristimulus colorimeter show average errors in the range of $\Delta u'v'$ from 0.001 to 0.005. The tolerance limits are far below the perceptible limit of the human eye (Figure 8) [5].

$\Delta u'v'$	**Tristimulus colorimeter results**
Red	0,00194
Green	0,00060
Blue	0,00120
Red+Green+Blue	0,00550

Figure 8: Tristimulus colorimeter measurement results for RGB LED Illumination

4. Calibration tools for mobile smart photonic measurement systems

In the international vocabulary of metrology the definition of calibration sounds (VIM 2.39): Calibration is an operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

Mobile calibration tools are designed to reach the capabilities, performance, and ease-of-use of mobile smart photonic measurement systems. There are various kinds of photonic calibration tools for dimensional (Figure 9) [6], color (Figure 10) [7], [8], [9], [10] and spectral (Figure 11) [11], [12] measurements.

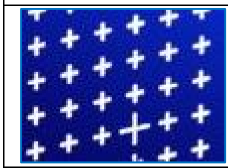
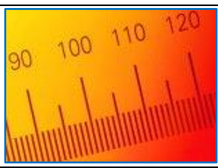
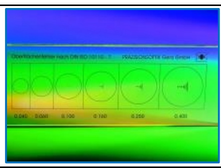
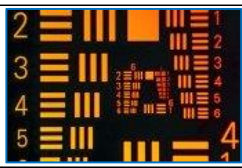
Mobile calibration tools for dimensional measurements				
				
Holes, dots and pattern	Glass scales	Surface detect pattern	USAF Testcharts	Siemens Stars

Figure 9: Calibration tools for mobile smart photonic dimensional measurement systems

Mobile calibration tools for color measurements				
				
Calibration LEDs	X-Rite Colorchecker	RAL Color Fan	VIS color liquids	VIS color glasses

Figure 10: Calibration tools for mobile smart photonic color measurement systems

Mobile calibration tools for spectral measurements				
				
Radiometic sources	Wavelength sources	Reflectance standards	UV-VIS-NIR liquids	UV-VIS-NIR glasses

Figure 11: Calibration tools for mobile smart photonic spectral measurement systems

5. Conclusion

In summary, calibration practices have to ensure that the measurements and their results obtained by one system are comparable with those obtained by a similar measurement system under similar measurement conditions.

Especially for mobile photonic measurement systems with the above mentioned sensors objective, reproducible and comparable mobile calibration tools are necessary. Examples for these kinds of calibration tools have been shown.

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