Benefits of Spectroradiometry for Color Measurements

Introduction

Insuring that today's self-emissive technologies, whether they be information displays, LED lighting, digital projectors meet or exceed performance specifications requires precise characterization through accurate measurements.

Several measurement technologies are available for device characterization, however two of the most widely instrument types include filter colorimeters and spectroradiometers including photometers, colorimeters and spectroradiometers but which one is best?

Filter Colorimeters

A basic filter colorimeter consists of:

Collection Optics
This could be a lens, contact probe, translucent disc or integrating sphere depending on the application.

Detector
A light sensitive device that converts photons into electrons. A colorimeter may contain three or more detectors. Detectors are typically PMT's (photomultiplier tubes) or silicon photodiodes.

Tristimulus filters
Red (two lobes X/red and X/blue), Green (Y) and Blue (Z) absorptive filters designed to create, together with the xdetector, the CIE (Commission internationale de l'éclairage or International Commission on Light) Color Matching Functions to match the color vision capabilities of the cone cells of the human eye. These functions are also known as the CIE Standard Observer.

Figure 1 is a detailed illustration of an advanced filter colorimeter with rotating filter wheel. Each position in the wheel contains a Red, Green or Blue CIE filter. Sequential measurements are made through each filter to obtain the CIE tristimulus values X, Y, and Z. Colorimeters of this caliber are supplied with hand matched CCIE filters. Even so they lack the color accuracy of spectroradiometers.

The CIE recommends the following equations for determining the Red (X), Green (Y) and Blue (Z) values for any given color stimulus:

\[
X = \int_360^{830} R(\lambda)X(\lambda)\Delta(\lambda) \quad \text{EQ 1}
\]

\[
Y = \int_360^{830} R(\lambda)Y(\lambda)\Delta(\lambda) \quad \text{EQ 2}
\]

\[
Z = \int_360^{830} R(\lambda)Z(\lambda)\Delta(\lambda) \quad \text{EQ 3}
\]
Figure 2 - CIE XYZ Color Matching Functions

Where \( R(\lambda) \) is the spectral power, \( X(\lambda), Y(\lambda), Z(\lambda) \) are the CIE Color Matching Functions and \( \Delta(\lambda) \) is the data increment in nanometers.

The ultimate goal of the filters utilized by filter colorimeters is to modify the detector’s spectral responsivity to the desired function. Filters are typically constructed as laminates (multi-layered) or thin film deposit.

Figure 2 is a typical silicon photodiode response curve illustrating how much of a change is required to modify the detector’s spectral responsivity to create the Tristimulus functions necessary to conduct CIE chromaticity measurements.

Figure 2 - Silicon Photodiode Responsivity

Colorimeter Benefits

The primary benefit of a filter colorimeter is speed, especially in those models that feature multiple detectors. For these instruments, each detector has its own CIE color filter and measurements are conducted in parallel. Other colorimeter designs feature a single detector and perform sequential measurements through each filter.

Colorimeter Drawbacks

Inaccuracies due to filter mismatch, of the difference of the responsivity of the instrument to the target response functions, especially for devices that differ spectrally from the standard used for calibration is the major drawback of a colorimeter.

Spectroradiometers

Instead of collecting color data utilizing absorptive filters, a spectroradiometer breaks up the incoming signal into an intensity per wavelength spectrum much like a prism converts sunlight into a rainbow. Multiple detectors then measure each color in the diffracted spectrum. This “raw data” into spectral radiometric values such as \( \text{W/sr/m}^2 \). From the corrected spectral values, the CIE color calculations are performed (EQ 1-3).
Spectroradiometer Benefits
Since a spectroradiometer does not rely on absorptive filters for color accuracy, a spectroradiometer is superior to that of a filter colorimeter regardless of the spectral power distribution of the source being measured. As an added benefit, a spectroradiometer can provide information that is impossible for a filter colorimeter – the spectral power distribution of the source.

To the right are several measurements made of a white LED through neutral density filters being displayed as a semi-log graph. Note how the spectral signature changes as the density of the filter increases.

Photo Research Spectral Solutions
Photo Research has been providing spectral solutions for over 30 years and was one of the first to introduce the self-scanning or multi-element detector systems. Our top of the line systems, the PR-7 Series, features thermo-electrically cooled detectors for stability, up to eight measuring apertures and an AutoSync feature which insures accuracy is maintained regardless of the frequency characteristics of the display. The PR-740 is the most sensitive in it’s class with an incredible threshold sensitivity of 0.000015 cd/m² – sensitive enough to measure an OLED display being commanded to 0,0,0! Our newest member of the PR-7 family, the PR-788 features an incredible dynamic range of 500,000,000:1 making it the solution of choice for spectrally based contrast testing of any commercially available display product.

The PR-6 series features battery powered portability, small footprint and hand-held operation. The PR-680 features a dual detector – a diode array and photomultiplier (PMT) making it possible to perform highly accurate spectrally based color and temporal (rise time, flicker) measurements with the same instrument.

All PR-7 series solutions are available with a feature found nowhere else – automated variable bandwidth. The bandwidth of a spectroradiometer is controlled by the dimension of the spectrometers exit slit and the resolution of the diffraction element (grating). Spectral bandwidth is measured at Full Width Half Maximum (FWHM), of the peak value. Figure 3 is the result of a measurement with a PR-740 of a HeNe laser (632.8 nm) with the variable bandwidth feature. Note that although the peak is lower for the 4 and 8 nm measurements, the area under each curve is equal.
Conclusion

When going through the process of selecting a chromaticity measurement solution, it is important to consider not only the price of the solution, but also the accuracy. It might seem fiscally responsible to spend as little as possible on a filter colorimeter that will provide the numbers you need to drive down testing costs. At the end of the day, the low cost solution may very well cost far more in rework than a top-end spectral solution when your customer rejects your product because the low priced solution “lied” to you.

For more information regarding spectroradiometer solutions offered by PHOTO RESEARCH, please visit our web site at www.photoresearch.com or call us at 818-725-9750.