The Spectrally Tunable LED light Source – Design and Development Issue

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Abstract. A spectrally tunable light source using a large number of LEDs and an integrating sphere has been developed at the National Institute of Standards and Technology (NIST). The source is designed to have a capability of producing any spectral distribution, mimicking various light sources in the visible region by feedback control of the radiant power emitted by individual LEDs. The spectral irradiance or radiance of the source is measured by a standard reference instrument; the source will be used as a transfer standard for colorimetric, photometric and radiometric applications. Source distributions have been realized for a number of target distributions.

Introduction

Photometric and colorimetric quantities of a light source can be measured with a spectroradiometer (calculated from its spectral power distribution) or with a photometer or a colorimeter that have a relative spectral responsivity approximated to the spectral luminous efficiency function, $F(\lambda)$, or the color matching functions defined by the CIE1, 2. The spectral correction filter is an essential component of a photometer or colorimeter. Tristimulus colorimeters typically use three or four channels of detectors with filters to mimic the CIE color matching functions. No photometer or colorimeter exactly matches their spectral responsivities to $F(\lambda)$ or the color matching functions. Due to this imperfect matching of the spectral responsivities, measurement errors are inevitable. These measurement errors can increase dramatically when the relative spectral power distribution (SPD) of a test source is dissimilar from that of the calibration source. Such spectral mismatch errors will be minimized by calibrating the photometer or colorimeter with standard sources having similar spectra as the source to be measured. Spectroradiometers also have various sources of error including stray light, and these errors can be minimized by calibrating the instrument with a standard source having similar spectra as the source being measured.

A spectrally tunable source, capable of matching the Spectral Power Distribution (SPD) of a variety of light sources, including daylight illuminants, with high spectral fidelity. In this paper, we present the construction and performance of the LED-based STS that has been developed.

1. Construction of the STS

The STS (Fig. 1) is an integrating sphere source illuminated by a large number of LEDs having different spectral peaks and distributions. The sphere (30 cm diameter) has an opening of 10 cm maximum diameter. The LEDs can be driven and controlled individually with a 256 channel, computer-controlled power supply. The large number of spectral channels helps facilitate accurate matching of fine structure in target source SPDs.

2. Spectral matching algorithm

An algorithm was developed to achieve the best matching of the output spectrum of the source to any input target spectrum. In the optimization, the values of power coefficients $k_i, i=1...n$ for the n different LEDs are determined. The power coefficient $k$ is strongly related to the current applied to, or radiant flux from, the LED belonging to that variable. The resulting spectrum is the sum of all LED SPDs, weighted by the $k$’s calculated according to the optimization algorithm.

The optimization consists of the following steps:
1) Select the initial values of power coefficients \( k_i^{(0)} \), \( i = 1 \ldots n \) of \( i \)-th LED; they can be any positive number.

2) Calculate the \( j \)-th value of \( k_i \) from the \((j-1)\)-th value, based on the partial derivative with respect to \( k_i \) of the square of the difference between the target spectrum and the STS spectrum built up from the LED spectra weighted by the variables \( k \):

\[
k_i^{(j)} = k_i^{(j-1)} - a \frac{\partial}{\partial k_i^{(j-1)}} \left[ \sum_{\lambda=380}^{780} k_i^{(j-1)} s_{LED}(\lambda) - S_{TARGET}(\lambda) \right]^2.
\]

where \( a \) should be between 0 and 1. To achieve an optimal calculation time while still ensuring convergence of the solution, \( a \) parameter was set to 0.001.

3) Continue the iterations until the solution converges, i.e. when

\[
\sum_{\lambda=380}^{780} \sum_{i=1}^{n} k_i^{(j)} s_{LED}(\lambda) - S_{TARGET}(\lambda) = \sum_{\lambda=380}^{780} \sum_{i=1}^{n} k_i^{(j-1)} s_{LED}(\lambda) - S_{TARGET}(\lambda)
\]

The equality is obtained from a large number of iterations where the individual LED currents (power coefficients \( k \)) are increased or decreased in small increments. It can be interpreted that the algorithm stops when the values \( k \) reach a steady-state solution. The individual LED currents are obtained from the optimization. The integral-sum of the differences at each wavelength is an indication of the quality of the realized spectral match.

3. Realized STS spectral distributions

Figs. 2 to 4 shows examples of the output spectra of the STS source matched to the given spectra. The deviations from the given spectra are mainly caused by limitations in the availability of LEDs with the appropriate peak wavelengths, their finite spectral widths (SPD curves), as well as drifts due to temperature dependence, instability, and aging of the LEDs. The matching will be improved by changing the selection of LEDs used. The average luminance of the STS, which depends on the specific spectral distribution desired, is between several hundred and one thousand [ cd·m\(^{-2}\) ]. Further results of characterization of the STS source developed will be presented in the full paper.

4. Conclusions

A spectrally tunable LED source (STS) has been developed. The source can approximate various CIE illuminants (D65, etc.) as well as common source spectral distributions for other photometric and colorimetric applications, and may be useful for visual experiments on colorimetry as well.

References