Uniformity Calculations for Uniform Sources

Background

Quantifying the uniformity of a uniform source system provides a measure of the spatial quality of the light field that is being used for correcting image sensors. In some cases, a single value is sufficient, while in others, a complete map of the spatial variation with quantitative values for a prescribed spatial resolution is required. This range of use-cases requires different measurement and calculation methods to adequately describe the spatial distribution of the source.

Measuring Uniformity

For radiance measurements, Labsphere measures uniformity by taking an image of the source field with a Westboro Photonics WP640 Imaging Colorimeter that has been flat-fielded in the Labsphere optical calibration laboratory. This image produces a grid of 2048 x 2048 pixels which is then subdivided into an 11 x 11 spatial grid that occupies 90% of the source diameter. An edge-detection algorithm defines this 90% region and the pixels are then averaged within the 89 resulting regions in the 11 x 11 grid space.

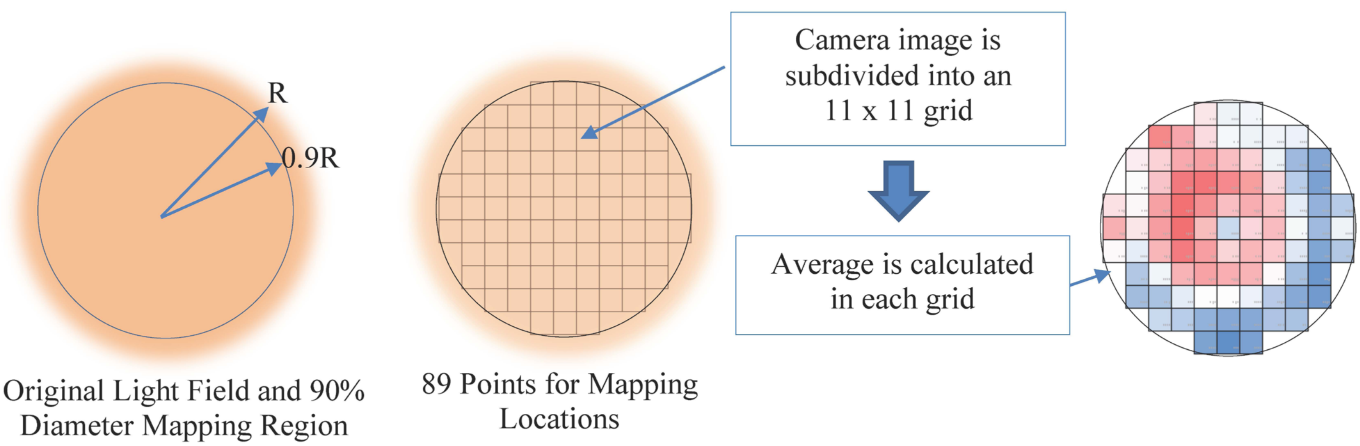

Figure 1 Mapping procedure for 11 x 11 grid of 89 points

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Calculating Uniformity

Uniformity is described as the lack of variation in the distribution of radiance levels across the source. The term *non-uniformity* is used to describe the deviation of the radiance from the mean across the area of interest. Perfect uniformity has a value of 1.0 (100%) indicating that all radiance levels are equal.

Uniformity: CoV Method

Labsphere has standardized on the Coefficient of Variation method (CoV) to describe the uniformity of a source which is consistent with the method at NIST [1]. This value describes the statistical dispersion of the variation in luminance over the space relative to the mean value and is calculated as:

$$Uniformity_{COV} = \left(1 - \frac{\sigma_L}{\bar{L}}\right) \times 100\% \quad (1)$$

$$\bar{L} = \frac{1}{N} \sum_{i=1}^{N} L_i \quad (2)$$

$$\sigma_L = \sqrt{\frac{\sum_{i=1}^{N} (L_i - \bar{L})^2}{N}} \times 100\% \quad (3)$$

where L_i is the measured radiance or luminance for a given element, $\bar{L}$ the mean radiance of N elements in the measured space, and σ_L the standard deviation.

Max Deviation Method

This method uses the ratio of the minimum to maximum luminance values to calculate uniformity and is the method that will generate the lowest quantity for uniformity since it utilizes the extreme variations from the radiance field. This is the method that Labsphere has primarily used prior to the release of this document to describe the uniformity of our systems.

$$U_{Max\ Deviation} = \frac{Min}{Max} \times 100\% \quad (4)$$

This form can also be written as:

$$U_{Max\ Deviation} = 1 - \frac{(Max - Min)}{Max} \times 100\% \quad (5)$$

Mean Deviation Method

This method provides a measure of the mean deviation relative to the average:

$$U_{Mean\ Deviation} = 1 - \frac{\left(\frac{Max - Min}{2}\right)}{Mean} \times 100\% \quad (6)$$

Deviation Method

This method provides a measure of the total deviation from the average:

$$U_{Deviation} = 1 - \frac{(Max - Min)}{Mean} \times 100\% \quad (7)$$

Uncertainty in Uniformity Measurements

Labsphere has developed a method for calculating the uncertainty in uniformity measurements that utilizes the Monte Carlo Method (MCM) for calculating the propagation of uncertainty through the entire calibration and measurement procedure.[2] Uncertainty was found to increase with higher grid resolution due to less averaging of the individual pixel variations. In general, the uncertainty in the measured uniformity for all methods was very low and ranged from ±0.0046% to ±0.33% (k=2) for the systems considered that had uniformity in the range of 98 – 99%. Uncertainty estimates refer to the measurement, not the process, so the uncertainty in any measured uniformity will be unique. These values may be used for general reference.

Specifying a Uniformity Requirement

When defining the required uniformity for an application, it is imperative to consider significant figures in the requirement as well as the uniformity calculation method. Three significant figures is suggested when specifying the required uniformity; e.g. ≥ 97.5%. Based on the uncertainty estimates, uniformity is typically reported to four significant figures in the Labsphere Calibration reports and is then rounded to the significant figures of the requirement. For example, if a request is made to achieve 99% uniformity or better, a measured uniformity of 98.56% will be rounded to 99% as the reported value compared to the requirement. This rounding procedure is consistent with the NIST method in Reference 3.

In addition to the required uniformity value, the operating condition of the system at which uniformity is to be measured should also be specified. Uniformity can change with light level and lamp combinations, so understanding the uniformity at these different operating points may be important, depending on the application.

Summary

Applications that utilize light sources for calibration, flat-fielding, or illumination, have different performance requirements and subsequently, varying methods by which to characterize the performance. As technology has advanced, Labsphere has led the way in not only creating the traceable sources that are used as standards of measurement, but also the methods by which to characterize the attributes of the system. Standard measurement procedures are prescribed, but depending on the application Labsphere can also recommend the most appropriate characterization method and figure of merit that accurately describes your system attributes and performance.

References

1 Prokhorov, A.V., and Hanssen, L.M., "Numerical modeling of an integrating sphere radiation source," Modeling and Characterization of Light Sources, C. Benjamin Wooley, Editor, Proceedings of SPIE Vol. 4775 (2002) SPIE 0277-786X/02.

2 Jablonski, J., Scharpf, D., Rabade, S., Dobrowski, L., Durell, C., and Holt, J., "Perfectly Understood Non-Uniformity: Methods of Measurement and Uncertainty in Uniform Sources," SPIE Defense and Commercial Sensing, April, 2019, Baltimore, MD.

3 "Good Laboratory Practice for Rounding Expanded Uncertainty and Calibration Values," NIST GLP 9, January, 2016.

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