

## Evaluate the performance of spectroradiometer using BCRA tiles

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**Abstract.** Color stability is the key goal during the process of color dissemination and replication. The results of color consistent can be influenced by many factors. In this project, we focused on the error caused by measurement instrument, i.e. spectroradiometer. According to the radiance data collected from six British Ceramic Research Association tiles under two different standard illuminants, i.e. illuminant A and illuminant CWF, the tristimulus value of different colors under different conditions of illuminants were calculated and used for computing the mean color different from mean of the six tiles. Last, the performance of stability and consistency of the spectroradiometer was evaluated. The result showed that the spectroradiometer under standard illuminant CWF outperformed than that under standard illuminant A.

### Introduction

There are numerous colors surrounded in our daily life. However, different people may have different feeling of colors, like when we talks about the light blue, we may have imagined dozens of light blue in our mind. This phenomenon can be explained in the way that color is a sensation [1], which is not the nature attribute of an object. The three properties of color, that are hue, lightness and saturation [2], can only describe the color in general while it is challenge to communicate the color.

In the past decades, the field of image transmission develops increasingly. As we mentioned before, color is a sensation which is hard to describe, which results in the development of quantitative methods instead of qualitative ways in order to get the precise color description and facilitate the work-flow of color reproduction. As we know, the color is formed in our eyes system when they capture the reflectance of objects under some illuminants. That means without the light there will be no colors. So the researches of spectral colors become more and more popular.

In this paper, an experiment was introduced to get the radiance data of spectroradiometer when measuring six different colors BCRA tiles under standard illuminant A and illuminant Cool White Fluorescent (CWF). Then through computing the mean color different from mean (MCDM) of the six colors, the performance of stability and consistency of the spectroradiometer was evaluated.

### Background

The results of color consistent can be influenced by many factors, such as the process of printing, gamut difference between original and output. However, in this project, the error caused by spectroradiometer was focused on. There are many performances of spectroradiometer that can describe the quality itself, which have been addressed in ASTM E2214-02. Among this, stability and consistency [3] were focused on in this project.

Stability or repeatability is the ability to produce the same results during a certain span of time [4]. Short-term, medium-term and long-term repeatability determined from seconds to minutes, from hours to days and from weeks to months are distinguished. In our project, we exploited the short-term method due to the limited time.

Consistency describes the ability of an instrument to generate the same result as a reference instrument. However, in our study, we measured several different positions in each tile to check

whether the results were changeable or not.

A spectroradiometer is used to measure spectral radiance or irradiance across the spectral ranges from approximately 380nm to 780nm. It is often used as a reference instrument in research and development of laboratories because its high accuracy and portability [5]. And the radiance data will be processing by the formula (1) as following:

$$\begin{aligned} X &= k \sum_{\lambda=380}^{780} I(\lambda) \bar{x}(\lambda) \\ Y &= k \sum_{\lambda=380}^{780} I(\lambda) \bar{y}(\lambda) \\ Z &= k \sum_{\lambda=380}^{780} I(\lambda) \bar{z}(\lambda) \end{aligned} \quad (1)$$

Where,  $I(\lambda)$  represents spectral radiance;  $\bar{x}(\lambda)$ ,  $\bar{y}(\lambda)$ ,  $\bar{z}(\lambda)$  represent Color-matching functions of CIE 2° Standard Observer (1931) and  $k$  represents a normalizing constant, which equals to 683.

This formula above can be used to calculate the radiance data to tristimulus values XYZ [6]. In order to compute the color difference to illustrate the tendency of these data, we need to transfer the XYZ values to a uniform color space, i.e. CIE L\*a\*b\*, to get the LAB values. Since the function in the matlab use D50 as default illuminant, we need to define our illuminant as reference illuminant. Last, computing the mean color difference from the mean (MCDM) [7], which are calculated between the mean of the measurements taken and each individual measurement. The formula (2) is as following:

$$MCDM = \frac{1}{n} \sum_{i=1}^n \sqrt{(L^* - \bar{L}^*)^2 + (a^* - \bar{a}^*)^2 + (b^* - \bar{b}^*)^2} \quad (2)$$

In this study, the well-known mean color difference from the mean (MCDM) is used for univariate repeatability evaluations. It describes the average deviations of several measurements from their mean value. The mathematical operation is transferred to the evaluation of stability and consistency [3].

## Experiment

**British Ceramic Research Association (BCRA) tiles [8].** The set of BCRA tiles is meaningful for spectroradiometer evaluation, because it has a wide range of rich colors, the tiles are readily cleaned, and (except for some well characterized anomalies with temperature) very stable. A set of tiles can be measured by many methods with different color devices, and can be assumed that the tiles, if properly measured, will not change characteristics over a long period of time, such as a few years. As a result, they are widely used as a means to validate spectroradiometers (to establish the accuracy of a spectroradiometer) and to quantify the degree to which it agrees with other spectroradiometers.

**Setup.** In order to answer whether the data measured by spectroradiometer are stable and consistent, an extensive study comparing the radiance of BCRA tiles under illuminant CWF and illuminant A using the device spectroradiometer and software specbos radiometric USB V4 were performed. Six test samples were used in the study: White (W), Red (R), Green (G), Light blue (LB), Yellow (Y), and Orange (O). The whole process of experiments was conducted in a controlled dark room. Two sets of measurements were made on each sample tile:

Step 1: Measure one still position for 25 times, that is the position A showed in Fig. 1 (the results were used for evaluating the performance of stability of spectroradiometer);

Step 2: Measure four corners and one center of each tile for 5 times and the order is A, B, C, D, E showed in the Fig. 1 (the results were used for evaluating the performance of consistency of spectroradiometer).

So a total of 540 measurements (including the while tile which used for reference illuminant) were made in this study, which means the five times measurement of position A can be used for both evaluation on stability and consistency. Then for each tile can only need measure 45 times instead of 50 times under one illuminant.

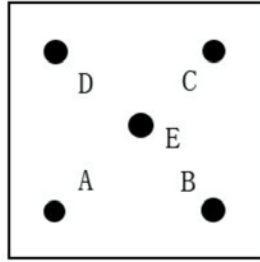


Fig.1. The overview of measure position in each BCRA tile.

## Results and Analysis

As mentioned before, this project is aiming to evaluate the spectroradiometers stability and consistency by measuring the BCRA tiles during short-term under illuminant A and illuminant CWF. Those radiances data are showed in Fig. 2.

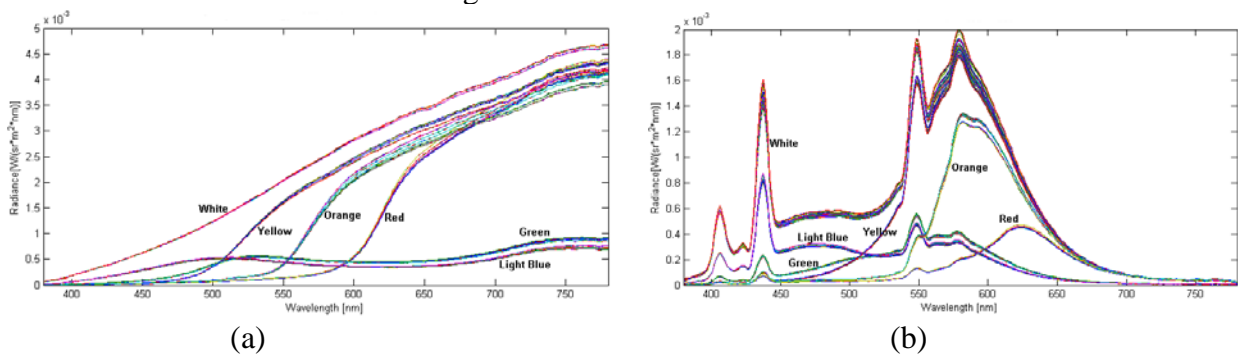


Fig. 2. (a) The radiances distribution of six BCRA tiles under illuminant A. (b) The radiances distribution of six BCRA tiles under illuminant CWF.

As for the white tile, after measuring 45 times, the summing radiance and matching formula (1) were used to calculate the corresponding tristimulus values XYZ and get the mean value from them. Then use the function xyz2lab in the matlab to get the LAB values in the uniform space CIELAB. As the function in the matlab use D50 as default illuminant, the reference illuminant need to be defined by ourselves. In our experiment, we used the mean LAB of white under each illuminant as our reference illuminant. The MCDM results were showed in Fig. 3.

**White tile.** As it showed in the Table 1, based on the stability of MCDM 0.37 under standard illuminant A, which was lower than that 0.52 under standard illuminant CWF, and the tendency in the Fig.3 (a) was much flatter than that in the Fig. 3(c), we can know that in this case spectroradiometer was more stable under the standard illuminant A with respect to white tile.

However, according to the consistency of MCDM values, the results were not more consistent in the whole tile under the standard illuminant A than that under the standard illuminant CWF. And they both had higher value in the center showed on Fig. 3(b) and 3(d), especially higher deviation under standard illuminant CWF.

Table 1. The MCDM of each tiles under standard illuminant A and CWF

Illuminant	Performance	White	Red	Green	Light Blue	Yellow	Orange	Mean
A	Stability	0.37	0.40	0.29	0.39	0.52	1.10	0.51
	Consistency	0.68	0.69	0.52	0.69	0.79	1.46	0.80
CWF	Stability	0.52	0.16	0.20	0.20	0.26	0.45	0.30
	Consistency	0.57	0.42	0.44	0.48	0.58	1.05	0.59

**Red tile.** Based on the stability of MCDM 0.40 under standard illuminant A, which was higher than that 0.16 under standard illuminant CWF, and the tendency in the Fig. 3(a) was more fluctuant than that in the Fig. 3(c), we can know that in this case spectroradiometer was more stable under the standard illuminant CWF with respect to red tile.

According to the consistency of MCDM values, the results were not more consistent in the whole tile under the standard illuminant A than that under the standard illuminant CWF. But based

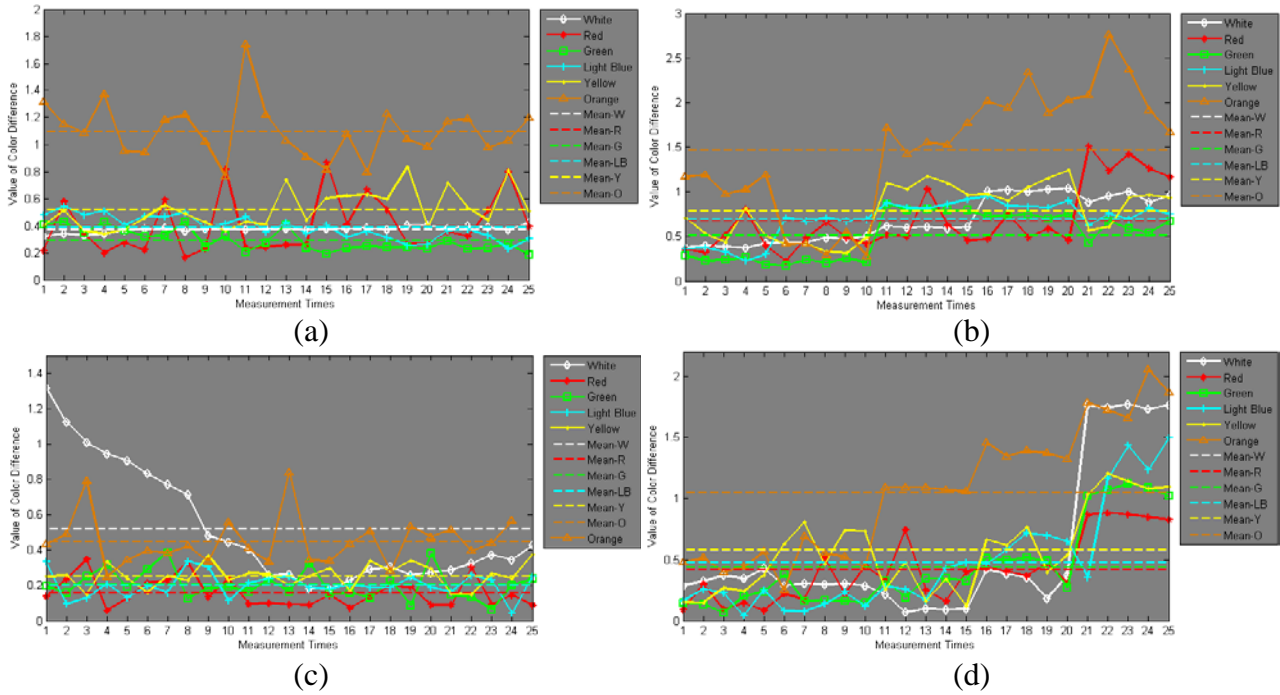


Fig 3. The overview of MCDM of six colors BCRA tiles under standard illuminant A and CWF. (a) Results of stability of spectroradiometer under illuminant A. (b) Results of consistency of spectroradiometer under illuminant A. (c) Results of stability of spectroradiometer under illuminant CWF. (d) Results of consistency of spectroradiometer under illuminant CWF.

on the tendency showed on Fig. 3(b) and 3(d), it showed that the results was more normal under standard illuminant A while more fluctuant under standard illuminant CWF. And they both had higher values in the center.

**Green tile.** Based on the stability of MCDM 0.29 under standard illuminant A, which was higher than that 0.20 under standard illuminant CWF, and the tendency in the Fig. 3(a) was much fluctuant than that in the Fig. 3(c), we can know that in this case spectroradiometer was more stable under the standard illuminant CWF with respect to green tile.

According to the consistency of MCDM values, the results were not more consistent in the whole tile under the standard illuminant A than that under the standard illuminant CWF. And based on the tendency showed on Fig. 3(b) and 3(d), it showed that the results deviated from the mean under standard illuminant CWF.

**Light Blue tile.** Based on the stability of MCDM 0.39 under standard illuminant A, which was higher than that 0.20 under standard illuminant CWF, and the tendency in the Fig. 3(a) was much fluctuant than that in the Fig. 3(c), we can know that in this case spectroradiometer was more stable under the standard illuminant CWF with respect to Light Blue tile.

According to the consistency of MCDM values, the results were not more consistent in the whole tile under the standard illuminant A than that under the standard illuminant CWF. However, based on the tendency showed on Fig. 3(b) and 3(d), it showed that the results deviated from the mean under standard illuminant CWF, especially in the central position.

**Yellow tile.** Based on the stability of MCDM 0.52 under standard illuminant A, which was higher than that 0.26 under standard illuminant CWF, and the tendency in the Fig. 3(a) was much fluctuant than in the Fig. 3(c), we can know that in this case spectroradiometer was more stable under the standard illuminant CWF with respect to yellow tile.

According to the consistency of MCDM values, the results were not more consistent in the whole tile under the standard illuminant A than that under the standard illuminant CWF. And based on the tendency showed on Fig. 3(b) and 3(d), it showed that the results deviated from the mean under standard illuminant A.

**Orange tile.** Based on the stability of MCDM 1.10 under standard illuminant A, which was much higher than that 0.45 under standard illuminant CWF, and the tendency in the Fig. 3(a) was

much fluctuant than in the Fig. 3(c). So we can know that in this case spectroradiometer was more stable under the standard illuminant CWF with respect to orange tile.

However, according to the consistency of MCDM values, the results were not more consistent in the whole tile under the standard illuminant A than under the standard illuminant CWF. While based on the tendency showed on Fig. 3(b) and 3(d), it showed that the results deviated from the mean under standard illuminant CWF.

## Conclusion and Prospect

In this project, we performed a color measurement work-flow of six different color BCRA tiles using spectroradiometer under illuminant A and illuminant CWF, which can be used to evaluate the performance of stability and consistency of spectroradiometer and standardize the device itself. The results showed that the data is much reliable since the MCDM values are small to be tolerated, from range [0.16, 1.46]. In general, the performance of stability and consistency of spectroradiometer under standard illuminant CWF outperformed than that under standard illuminant A. However, different colors under different illuminants will have different results. The MCDM of red tile showed that spectroradiometer performed better stability under standard illuminant CWF, while orange tile worse consistency under illuminant A. Besides, the orange color showed that the performance of spectroradiometer was worse than others colors.

There are many future work to do related this topic, such as using more devices to measure the BCRA tiles, involving more illuminants or other substitutes for BCRA tiles, and then can compare these data, which could give us more comprehensive illustration about spectroradiometer performances. Or we can also use more tiles to build a huge data set.

## Acknowledgment

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