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INFLUENCE OF THE ACCURACY AND PRECISION OF A REFLECTANCE SPECTRUM MEASUREMENT ON COLORIMETRIC VALUES

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Abstract: *In this work the influence of the accuracy and precision of handheld spectrophotometers on the outcome of the colorimetric measurement is shown. Five different spectrophotometers where evaluated in terms of the accuracy and precision. Statistically evaluated data was used to caluculate CIE L*a*b* values and colorimetric difference. The results show that the lower quality of the device may lead to inconsistency when measuring color difference.*
Key words*: Spectrophotometry, Colorimetry, CIE*

1. INTRODUCTION

Out on the market there are many different applications and devices used in ever growing color industry. It is now possible to make colorimetric measurement almost without any knowledge of the field whatsoever. Color spaces like CIE XYZ and CIE L*a*b* are used extensively in the broad spectra of applications from the publishing industry, over the paper industry, to the color industry. For mentioned applications, it is important to be capable to acquire colorimetric data in fast, easy, and precise way.

The usual colorimetric value used extensively in all industries that work with color is a colorimetric difference. It is the metric of difference between two measured color specimens. Since the colorimetric difference is so popular in color industry, it is important that a measuring device has a sufficient measuring accuracy and precision to minimize its influence on the calculated colorimetric difference.

The goal of this paper is to evaluate the measuring precision and accuracy of different spectrophotometers and show the influence that they have on colorimetric difference.

The rest of the paper is organized as follows. In chapter 2 a theoretic background is given. Chapter 3 explains the experiment. The chapter 4 concludes the experiment with the results and discussion.

2. BACKGROUND

A measuring device should be both, accurate and precise. The accuracy of a measurement device is the degree of closeness of measurements of a quantity to its actual (true) value. The precision of a measurement device is the degree to which repeated measurements under unchanged conditions show the same results (Taylor, 1999).

2.1 Accuracy

Therefore, the accuracy of a spectrophotometer can be defined as the difference between the mean value of measurements and the reference value:

$$A = R_0 - \frac{1}{n}\sum_{i=1}^{n} R_i \tag{1}$$

Where A is the accuracy, R_0 is a referent value, R_i is the ith measurement of spectral reflectance, and n is the number of measurements.

2.2 Precision

The precision of spectrophotometer can be defined as the variance of data accuired by measurements.

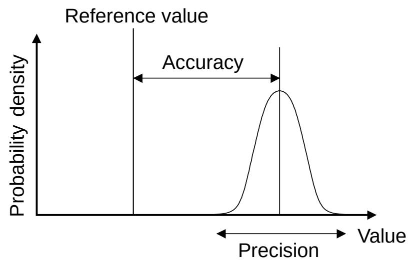

Fig. 1. The Accuracy and precision of a measuring device

As a metric for the evaluation of the measurement precision of a spectrophotometer a pooled standard deviation is used. Poled standard deviation estimates standard deviation of the several different samples of which mean may vary but the true standard deviation is assumed to remain the same (McNaught and Wilkinson, 1997):

$$\sigma_p = \sqrt{\frac{\sum_{i=1}^{k}((n_i-1)\sigma_i^2)}{\sum_{i=1}^{k}(n_i-1)}} \tag{2}$$

Where σ_p is pooled standard deviation, n is size of ith sample, and σ_i is standard deviation of the ith sample.

2.3 Colorimetric formulae

According to a tri-stimulus theory of the color perception color can be represented by three parameters such as CIE XYZ or CIE L*a*b* (Berns, 2000). These values are caluculated from a reflectance spectrum.

CIE L*a*b* values are defined as (Wyszecki and Stiles, 1982):

$$L^* = 116 f\left(\frac{Y}{Y_n}\right) - 16 \tag{3}$$

$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right] \tag{4}$$

$$b^* = 300\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right] \tag{5}$$

$$f(t) = \begin{cases} \sqrt[3]{t} & t > (\frac{6}{29})^3 \\ \frac{1}{3}(\frac{29}{6})^2 t + \frac{4}{29} & t \le (\frac{6}{29})^3 \end{cases}$$

Where L*, a* and b* represent, lightness, red-green, and yellow-blue coordinate respectively; X, Y, Z are the CIE XYZ tristimulus values of the sample; X_n, Y_n, Z_n are the CIE XYZ tristimulus values of the reference white point.

To show the influence of the accuracy and precision of a spectrophotometer in real life situations the colorimetric difference ΔE, should be used. It is defined as a geometric distance between two coresponding points in the CIE L*a*b* color space (Hunt, 1991).

$$\Delta E^* = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2} \qquad (6)$$

Where L_1*,a_1*,b_1* and L_2*,a_2*,b_2* are CIE L*a*b* values for the two colors that are compared.

3. EXPERIMENTAL

The experiment was conducted using five different spectrophotometers: iOne, Spectrolino and SpectroEye manufactured by Gretag Macbeth, Pulse and 939 Spectrodensitometer manufactured by Xrite. All measuring devices were calibrated according to manufacturer's recomendations.

Measurements were made on five color patches (cyan, magenta, yellow, black, and white) with an unknown spectral reflectance, and on the standard white reference patch with the known spectral reflectance. For each patch, and every spectrophotometer, 50 measurements were made. To have standard measuring conditions all spectrophotometers used D65 light source with 2° standard observer. The reflectance was measured from 400 nm to 700 nm with the interval of 10 nm. The temperature of the laboratory during measurement was held constant at 23 °C ± 2 °C which is within the manufacturers' recommendations.

For the acquisition of data from Gretag Macbeth iONE, Spectrolino and SpectroEye KeyWizard application was used. Xrite 939 and Xrite Pulse used ColorShop X application. However, to minimize any possible influence from using different applications, only spectral reflectance was acquired. With the acquired data, calculations for CIE L*a*b* values, and colorimetric difference ΔE were made using spreadsheet calculator.

The Acuracy of a spectrophotometer was determined by measurement of the standard referent white patch with known spectral reflectance. The accuracy was quantified using the metric of differance of its mean value and the referent value, for every interval, and for every color patch. As the estimate of the referent values of patches with unknown spectral reflectances, the mean values of spectral reflectance acquired with the spectrophotometer that showed the higest accuracy in the measurement of referent white patch was taken.

The precision of the spectrophotometer was determined by pooled standard deviation calculated from the measurements of the color patches.

To show the influence of the accuracy and precision for each pach CIE XYZ values, CIE L*a*b* values, and colorimetric difference between referent mean value and mean values of tested measuring devices were calculated. Since we did not know the reference values of the color patches with unknown spectral reflectance, we used the mean values of the most accurate spectrophotometer.

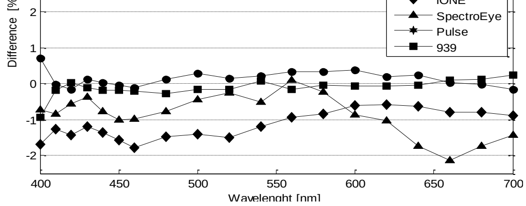

Fig 2. The plot of difference between mean spectral reflectances and the referent spectral reflectance

Device	medA	maxA	minA	std A	σ_p
Spectrolino	0,13	0,70	-0,15	0,22	0,05
iONE	-1,20	-0,58	-1,78	0,38	0,15
SpectroEye	-0,78	0,09	-2,13	0,57	0,10
Pulse	4,64	5,41	6,64	0,73	0,11
939	-0,12	0,24	-0,19	0,24	0,05

Tab. 1. Results of the statistical evaluation of measurement data

	mean	std	min	max	median
iONE	0,84	0,45	0,29	1,35	0,77
SpectroEye	0,78	0,44	0,34	1,28	0,69
Pulse	2,19	0,95	0,72	3,04	2,35
939	1,70	0,69	0,89	2,76	1,53

Tab 2. Results of the statistical evaluation of acquired data

4. RESULTS AND DISCUSSION

From table 1 it can be seen that the most accurate measurements gave Gretag Macbeth Spectrolino with the median and standard deviation of accuracy 0,13 and 0,22 respectively. Xrite 939 folows close behind. The worst results showed Xrite Pulse with the median of 4,64 and standard deviation of 0,73. These results are shown in figure 1, where is easy to see the difference of the mean of measured spectral reflectances and the referent spectral reflectance. Spectrolino and 939 had very accurate measurement through the whole spectrum, while other spectrophotometers show more deviation from the referent values.

The precision was estimated with pooled standard deviation of acquired data. The most precise measurements gave Spectrolino and 939 spectrophotometers with σ_p of 0,05, while the most inprecise whas iONE with σ_p of 0,15.

The influence of an accuracy and precison on colorimetric difference ΔE is shown in table 2. Pulse spectrophotometer, having the worst accuracy gave the largest colorimetric difference. Mean ΔE was 2,19 witch is unacceptable for serious use in color industry.

5. CONCLUSION

It can be concluded that the accuracy has significant influence on colorimetric difference. If the accuracy of the measuring device is not sufficient, it can give large colorimetric difference that can lead user to wrong conclusions about color results the user wants to evaluate. Main limitation of the research is the small number of evaluated spectrophotometers. However, even with the small evaluated set it is obvious that the quality of the device, in terms of the measurement precision and accurary, is very important for any kind of color evaluation. Therefore, a higher quality spectrophotometer is mandatory for work with color.

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