Performance of multi-angle spectrophotometers

Katharina KEHREN,[1] Philipp URBAN,[1] Edgar DÖRSAM,[1] Andreas HÖPE[2] and David R. WYBLE[3]

[1] *Institute of Printing Science and Technology (IDD), Technische Universität Darmstadt*

[2] *Physikalisch-Technische Bundesanstalt (PTB), Braunschweig*

[3] *Munsell Color Science Laboratory (MCSL), Rochester Institute of Technology*

Abstract

In high quality printing, special effect inks are used more frequently. Several multi-angle spectrophotometers have been developed for the measurement of such gonio-chromatic materials. This paper presents a study on the performance of commercial multi-angle instruments. We found that short-term is better than medium-term repeatability. Repeatability is better for a white reflection standard than for printed samples. Univariate and multivariate methods show the same geometry-dependent trends. Reproducibility and accuracy is less good for geometries with detection near specular direction.

1. Introduction

Due to their unique visual appearance, inks with special effect pigments (Pfaff 2007) are used more frequently for high quality printing e.g. in packaging. For process control and quality assurance of such gonio-chromatic materials, multi-angle spectrophotometers have been developed. In this study, the performance of three commercial multi-angle instruments was investigated using statistical parameters.

2. Background

The evaluation of the performance of colour-measuring devices using statistical parameters is explained in the ASTM E 2214 standard practice (2008).

Performance evaluations:

Performance is characterized by repeatability, reproducibility and accuracy.

Repeatability is the ability to generate the same results over a certain span of time. Short-term, medium-term and long-term repeatability determined from seconds to minutes, from hours to days and from weeks to months are distinguished.

Reproducibility stands for the ability of an instrument to generate the same results as another instrument. For evaluations on instruments with identical or different designs, inter-instrument and inter-model reproducibility are the corresponding specifications.

Accuracy describes the ability of an instrument to generate the same result as a reference instrument. Such instruments are found at National Metrology Institutes, e.g. the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany.

Statistical methods:

Univariate and multivariate statistical methods to quantify the performance of colour-measuring instruments are investigated by Wyble and Rich (2007a, 2007b).

Univariate methods estimate one single statistical variable with parameters like the mean value or the standard deviation. They are easy to handle and well established. Possible correlations to other statistical variables are ignored.

Multivariate methods typically use the covariance matrix to compute parameters such as the volume of the confidence ellipsoid. The relationship between statistical variables is considered. Chorro et al. (2009) investigated reproducibility of two multi-angle spectrophotometers using multivariate methods.

3. Measurements

The robot-based gonioreflectometer at PTB was used for reference measurements (Höpe 2010). All measurements with commercial multi-angle spectrophotometers are performed at the Institute of Printing Science and Technology (abbrev. IDD) in Darmstadt, Germany.

Test sequences:

The measurements at IDD are organized in short-term and medium-term sequences.

Sixty short-term (ST) measurements were made as quickly as possible without replacement of the sample. The instruments were calibrated immediately prior to the sequence using the respective calibration standards and manufacturer procedures.

Medium-term (MT) measurements were made with replacement of the sample, five times per hour for six consecutive hours per day on five not necessarily consecutive days. The calibration was performed once per hour before each set of five measurements.

Measured samples:

The three samples measured in this study are a white standard (WS) and two solid prints of an interference effect ink on a white paper (WP) and black paper (BP).

Evaluated instruments:

BYK-Gardner's BYK-mac, Datacolor's Multi FX10 investigated by Hupp and Dörsam (2006) and X-Rite's MA98 are the three multi-angle instruments examined in this study.

4. Evaluations

For multi-angle spectrophotometers, performance parameters have to be determined for more than one geometric configuration of light source, sample and detector.

Mean colour difference and ellipsoid volume:

In this study, the well-known mean colour 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 reproducibility and accuracy. We use measurements with another commercial instrument or with the reference instrument instead of the mean. The resulting parameters are called mean colour difference between instruments (MCDI) and mean colour difference to the absolute (MCDA), respectively.

For multivariate evaluations of reproducibility, Wyble and Rich (2007a) use the volume of the confidence ellipsoid for a confidence level of 95 %. We denote the ellipsoid volume for deviations from the mean as EVM in this study. Replacing the mean as described above yields to the ellipsoid volume for deviations between instruments (EVI) and the ellipsoid volume for deviations to the absolute (EVA).

Geometric coniqurations and parameter illustration:
The performance is evaluated for six geometric configurations realized in all instruments. The light source is located at an incidence angle of 45°. The aspecular angle, i.e. the angular difference between specular and detection direction, takes values of -15°, 15°, 25°, 45°, 75° and 110°. The itemized performance parameters are illustrated in a polar coordinate system. The angular coordinate indicates the aspecular angle. The radius vector specifies the value of the statistical parameter.

5. Results

The polar-like plots are used to analyse the influences of test sequence, measured sample, statistical method and geometric configuration.

Short-term versus medium-term test sequence:
As shown in figure 1a, short-term (ST) repeatability is better than medium-term (MT) repeatability. Presumably, the replacement of the sample between the individual MT-measurements is the reason instead of temporal deviations of the instrument. To exclude this influence, the following evaluations are based on ST-measurements.

White standard versus printed samples:
The repeatability for the white reflection standard is much better than for the printed samples as shown in figure 1b. The standard practice recommends repeatability evaluations for a white plaque only. Thus, instrument manufacturers specify repeatability for a white sample. In the light of our results, this seems to be not sufficient.

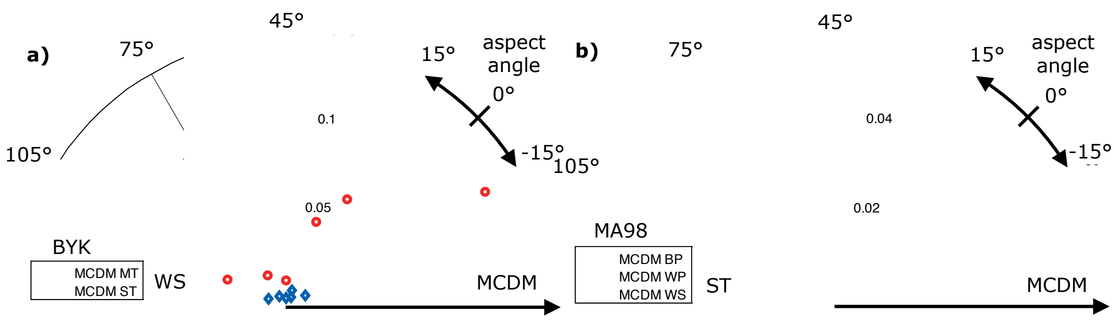

Figure 1: MCDM for a) MT- and ST-measurements with instrument BYK on sample WS and b) ST-measurements with instrument MA98 on samples BP, WP and WS.

Univariate versus multivariate methods:
To compare univariate MCDA and multivariate EVA, we normalize the maximum value to one. $MCDA_{NORM}$ and EVA_{NORM} are shown in figure 2a for two combinations of instrument and sample. For both pairs, the curves have almost similar shape. Univariate and multivariate methods show the same geometry-dependent performance tendency.

Near-gloss versus far-from-gloss geometries:
The influence of geometry is highlighted in figure 2b by means of the MCDA. For all samples and instruments, the MCDA and MCDI are high at low aspecular angles. Thus, reproducibility and accuracy are poor for geometries with detection near specular direction. Further investigations on the reason of the deviations are necessary.

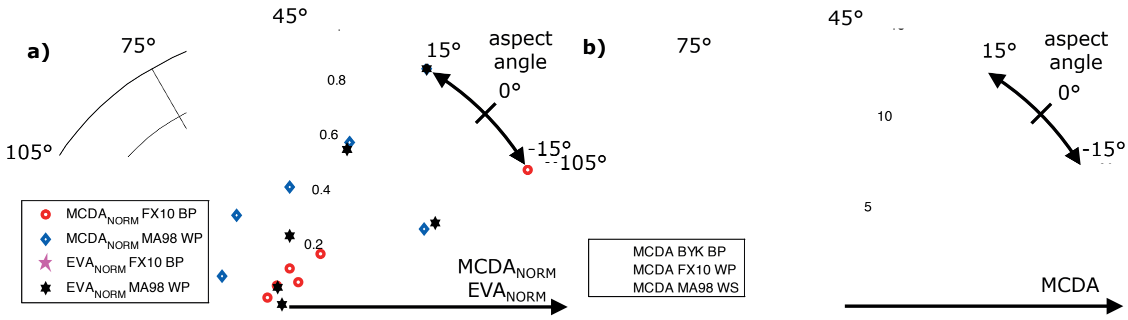

Figure 2: a) $MCDA_{NORM}$ and EVA_{NORM} and b) MCDA for ST-measurements with instruments BYK, FX10 and MA98 on samples BP, WP and WS.

6. Conclusion

A study on the performance of three commercial multi-angle spectrophotometers is presented. Short-term repeatability is better than medium-term repeatability. Compared to printed samples, repeatability is better for the white reflection standard. Univariate and multivariate methods show the same angle-dependent trends. Reproducibility and accuracy are less good for geometries with detection near the specular direction.

Acknowledgments

The authors thank Astrid Bothner, Kai-Olaf Hauer, Ludger Fischer and Uwe Schröder.

References

ASTM E 2214. 2008. Standard Practice for Specifying and Verifying the Performance of Color-Measuring Instruments. *ASTM International*. West Conshohocken. 1-10.

Chorro, E., E. Perales, V. Navarro, N. Alcón, A. Rabal, and F.-M. Martínez-Verdú. 2009. Reproducibility comparison between two multi-gonio-spectrophotometers. In *AIC 2009, Proceedings*, ed. by D. Smith, P. Green-Armytage, M. A. Pope, and N. Harkness. CD. Sydney: Colour Society of Australia.

Höpe, A., and K.-O. Hauer. 2010. Three-dimensional appearance characterization of diffuse standard reflection materials. Metrologia 47(3): 295-304.

Hupp, H., and E. Dörsam. 2006. Measuring printed special-effect colours - First experiences with the Multi FX10 spectrophotometer. In *IARIGAI 2006, Proceedings*, ed. by W. H. Banks. Leipzig: Hochschule für Technik, Wirtschaft und Kultur. 121-138.

Pfaff, G., P. Gabel, M. Kieser, F. Maile, and J. Weitzel. 2007. *Spezielle Effektpigmente – Grundlagen und Anwendungen*. Hannover: Vincentz Network.

Wyble, D. R., and D. C. Rich. 2007a. Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part I: Repeatability. *Color Research and Application* 32: 166-175.

Wyble, D. R., and D. C. Rich. 2007b. Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part II: Reproducibility. *Color Research and Application* 32: 176-194.

Address: Katharina Kehren, Institute of Printing Science and Technology, Department of Mechanical Engineering, Technische Universität Darmstadt, Magdalenenstraße 2, 64289 Darmstadt, Germany
E-mails: kehren@idd.tu-darmstadt.de, urban@idd.tu-darmstadt.de, doersam@idd.tu-darmstadt.de, andreas.hoepe@ptb.de, wyble@cis.rit.edu