(REFEREED RESEARCH)

COMPARISON OF SPECTROPHOTOMETRIC AND DIGIEYE COLOUR MEASUREMENTS OF WOVEN FABRICS

Małgorzata MATUSİAK[1], Anetta WALAWSKA[2], Wioletta SYBİLSKA[1]

Institute of Textile Architecture, Lodz University of Technology, Lodz Poland
Textile Research Institute, Lodz Poland

Received: 08.02.2016 Accepted: 07.10.2016

ABSTRACT

Colour is a very important feature in the process of clothing design and manufacturing, from fabric selection to design completion. It is a crucial component of fashion that can have a transforming effect upon audience perceptions and reactions. A correct measurement of the colour of textile materials for clothing is the key to market success at a time when the supply of textile goods is significantly higher than the demand. In the clothing industry, correct colour measurement is crucial in at least two areas: appropriate selection of materials for clothing manufacture, in agreement with the design and fashion trends, and ensuring high colour durability of clothing products. While spectrophotometers are universally used for textile colour determination, they have some limitations which can be eliminated by the application of the DigiEye colour measurement system. This device is mostly used for the assessment of products different from textiles, such as foodstuffs, but efforts have also been undertaken to use it for measuring the colour of textile materials. The reports published to date show promising results. The aim of presented work was to analyse the possibility of a wide application of the DigiEye system in the clothing industry for colour and colour durability evaluation of fabrics. Woven fabrics were measured by means of a DataColor spectrophotometer and a DigiEye colorimeter in order to compare the results delivered by these instruments. The study demonstrated a statistically significant correlation of results from the spectrophotometer and the DigiEye. However, some differences between the spectral reflectance curves obtained by the two methods need further investigation.

Keywords: Colour measurement, spectrophotometer

Corresponding Author: Małgorzata Matusiak, malgorzata.mmausiak@p.lodz.pl

1. INTRODUCTION

Colour is a very important feature of textile materials. The majority of woven and knitted fabrics, especially for garment and decorative applications, are dyed or printed in various colours [1,2]. It is necessary to ensure that textile materials and clothing are of an appropriate colour, according to the designer's vision and fashion trends. Colour repeatability and reproducibility are also major problems in the textile and garment industry. Another related aspect is colour fastness, associated with resistance to fading or running due to the action of environmental factors, such as weathering, sunlight and artificial light, crocking, perspiration, dry-cleaning, ironing, dry heat, laundering, gas fumes, etc. [3]. Colour measurement of sewing threads is yet another major issue in industrial practice as thread colour may affect garment quality. The highest quality garments utilize a thread colour that matches the dominant colour in the fabric [4]. Furthermore, colour is a basic criterion in the classification of cotton raw materials [5].

Taking above into consideration, the measurement of colour of textile materials and garments should be considered one of the more important aspects of quality assessment. Different methods of colour evaluation are applied in textile practice; they can be broadly divided into instrumental and organoleptic (visual). Organoleptic assessment of colour is performed for cotton raw materials by specially trained experts [5]. In the garment industry, colours are typically evaluated visually. To overcome the variability of daylight, researchers developed viewing cabinets and light booths employing standard illuminants, so that samples could be viewed under invariable conditions while assessing colours against a standard [6]. However, visual colour assessments are encumbered with a high dispersion of results due to subjectivity. Among the instrumental methods of colour measurement of cotton, the HVI (High Volume instrument) line is commonly applied all over the world [5]. For other textile products, spectrophotometers are the most popular and widely recognized tools, providing colour data in the *L*a*b** colour space defined by the CIE (*Commission internationale de l'eclairage*). This is the most popular standardized colour space, being a mathematical transformation of the CIE XYZ colour space. The following colour coordinates can be determined by means of a spectrophotometer:

- *L** – lightness,
- chromaticity coordinates:
  - *a** – green/red,
  - *b** – blue/yellow,
  - *C** – chroma – an attribute of colour used to indicate the degree of departure of the colour from a grey of the same lightness [7],
  - *h* – hue angle – an attribute of visual perception according to which an area appears to be similar to one of the colours: red, green, yellow, and blue, or to a combination of adjacent pairs of these colours arranged in a circle [7].

There are also some reports concerning the application of the DigiEye system in textile colour measurement. DigiEye is a computer controlled digital camera system for measuring colour and capturing high quality repeatable images. With the DigiEye, one can acquire colorimetrically accurate images of two- and three-dimensional samples and save them as digital files. The DigiEye can provide reflectance and colorimetric data on samples with an ultra-small area and an irregular or curved surface [8–10]. After a calibrated digital camera takes a photograph, colour measurement is performed by the DigiEye software. Matusiak demonstrated that while the DigiEye can be used for measuring the colour of cotton raw materials, it is necessary to develop procedures for cotton sample preparation and measurement performance [11]. According to Lau et al., there is a strong correlation between colour coordinates from the spectrophotometer and DigiEye for fabrics [12].

One of the advantages of DigiEye is that it can measure a larger area of the investigated object, which is of paramount importance given that the colour patterns of printed fabrics may have a large repeat (Fig. 1), exceeding the measurement area of the spectrophotometers traditionally used for textiles (e.g., 30 mm in diameter).

While previously the often multi-coloured and complex nature of patterns and prints was mostly evaluated on a purely visual basis during production quality control, now the DigiEye enables objective instrumental assessment of patterns in context by a non-contact digital imaging system. In comparison to subjective visual colour assessment the DigiEye instrumental approach offers improved objectivity, consistency, and quality [13].

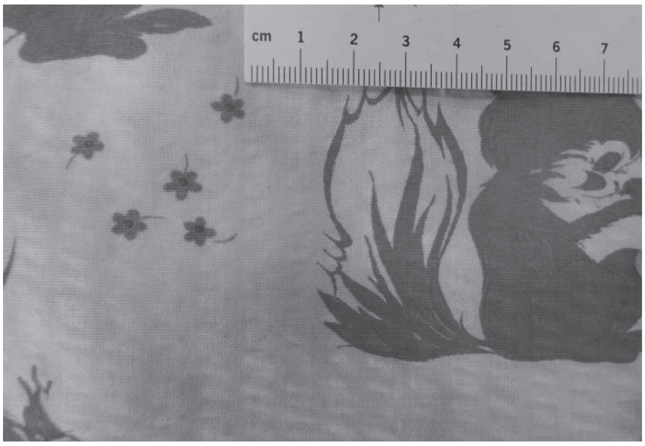

Fig. 1. Example of a woven fabric with a colour print larger than the measuring area of a spectrophotometer

In the authors' opinion, the measurement of the colour components of patterns and prints with a small repeat or those containing narrow strips (Fig. 2), small spots, checks of small repeat, and other shapes presents an even greater problem.

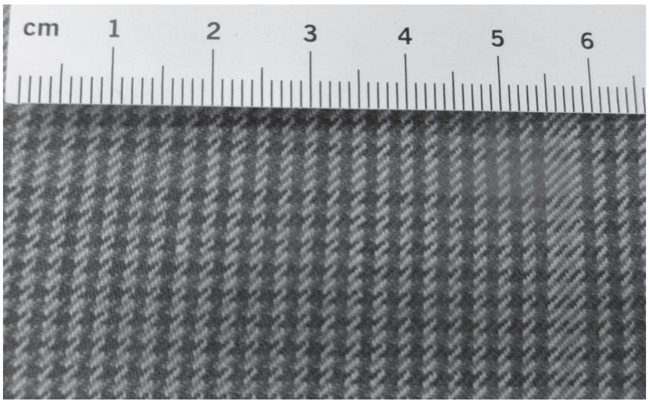

Fig. 2. Example of a woven fabric with colour strips of a width lower than the measuring diameter of a spectrophotometer

The smallest diameter of a spectrophotometer measurement area is different dependably on the type of device and aperture plate. In the DataColor spectrophotometers at the Ultra-Small Area View (USAV) aperture plate, the measured area is 2.5 mm, while the illuminated area of the sample is 6 mm. Consequently, it is difficult to prepare a fabric sample with a fine pattern for the measurement of individual colour components by means of a spectrophotometer. Thus, the application of the DigiEye is even more justified and necessary in the case of fabrics with fine patterns than in the case of those with large patterns.

The aim of the presented work was to measure the colour parameters of dyed woven fabrics by means of DigiEye and compare the results with those obtained from a spectrophotometer.

To enable inter-instrument agreement, manufacturers of colorimeters usually give the specifications of their devices with reference to a set of standards, such as BCRA CCS II (British Ceramic Research Association Ceramic Colour Standards Series II) tiles. The BCRA CCS II set offers a wide range of colours, including some samples in similar colours, which are useful for assessing the reproducibility of colour differences. These standards can be used to determine discrepancies between measurement instruments with respect to one another or to a master instrument, e.g., in order to verify the correct functioning of the device.

However, in contrast to ceramic colour standards, textile materials are characterized by elasticity, a porous structure and a heterogeneous surface in terms of smoothness and colour, which can influence colour measurements. In addition, finishing processes, and especially dyeing, can cause colour irregularity. Due to this, in order to determine whether the DigiEye system can be applied in the textile industry, inter-instrument agreement should be evaluated while measuring the colours of woven and knitted fabrics, which are the basic materials in the clothing industry.

2. MATERIALS AND METHODS

Colour measurement was performed for woven cotton and cotton/polyester fabrics dyed in different colours and designated for clothing manufacture. Such fabrics are typically subject to colour assessment in industrial practice. Fabrics in a wide range of colours were selected from the current collection of one manufacturer in order to eliminate the influence of industry-related factors on measurement results. While the investigated fabrics had different weaves, they were all starch-finished. The basic characteristics of the examined woven fabrics are presented in Table 1.

The fabrics were evaluated in terms of their colour by means of a DigiEye colorimeter and a Data Color 650 spectrophotometer.

Spectrophotometric measurements were performed under different standard CIE illuminants: D 65, A, and F 02. The D 65 illuminant represents natural daylight with a correlated colour temperature of 6500 K; the A illuminant is equivalent to a blackbody radiator with a colour temperature of 2856 K, and the F 02 illuminant represents fluorescent light with a correlated colour temperature of 4230 K [5,14]. Measurements were done for an area of 30 mm in diameter and a 10° observer. For each sample, colour measurements were done in 10 repetitions, with the final results calculated as an arithmetic mean and reported in terms of the CIE colorimetric values (*L*a*b*C**, and *h*) as well as spectral reflectance, ranging from 400 nm to 700 nm, at an interval of 10 nm.

The DigiEye system consists of a lighted cabinet, a calibrated Nikon D series digital camera, and a computer (Fig. 3). It provides complex colour data for a selected area of the image of the investigated sample. The colorimetric values *X*, *Y*, *Z*, *L**, *a**, *b**, *C**, and *h* are recorded against a selection of standard illuminants [5,14]. Similarly to a spectrophotometer, the DigiEye also measures spectral reflectance, ranging from 400 nm to 700 nm, at an interval of 10 nm.

Table 1. Characteristics of the investigated woven fabrics

Symbol	Colour	Raw material	Weave	Mass per square meter in g m^{-2}
T1	White	65 PES/ 35 CO	2/1 twill	246
T2	Grey	65 PES/ 35 CO	2/1 twill	239
T3	Red	65 PES/ 35 CO	3/1 twill	260
T4	Blue	65 PES/ 35 CO	1/1 canvas	192
T5	Khaki	CO	4/1 satin	310
T6	Hydron blue	CO	2/2 twill	310
T7	Cement	65 PES/ 35 CO	1/1 canvas	189
T8	Green	65 PES/ 35 CO	3/1 twill	300
T9	Royal (navy blue)	CO	3/1 twill	222
T10	Black	CO	3/1 twill	196

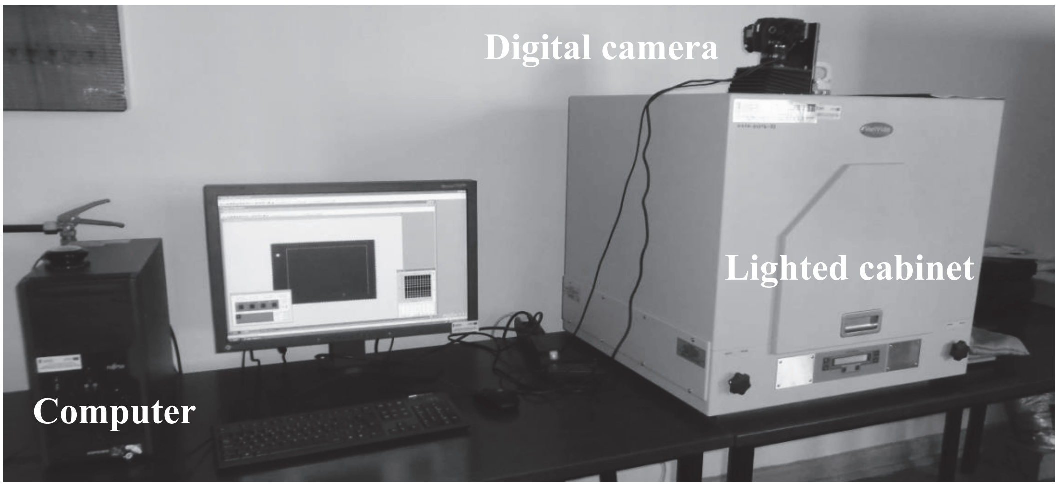

Fig. 3. DigiEye system for colour measurement

First, the sample to be measured, with a size of 140 mm × 210 mm, is placed in the cabinet (Fig. 4). The cabinet is lit by a combination of a fluorescent D65 illuminant and additive LEDs to produce a calibrated A-rated D65 simulator [10]. Next, an image of the sample is captured by a calibrated digital camera and analysed by the DigiEye software. Measurement is performed for the selected area of the investigated sample using the DigiPix option. The area can be defined using a free-form tool, a rectangle tool, or a circle tool.

In the presented study, a centred rectangular area covering the majority of the investigated sample was selected using the rectangle tool (Fig. 5).

3. RESULTS AND DISCUSSION

This section of the paper presents and discusses DigiEye and spectrophotometric results obtained with the D65 illuminant.

3.1. Spectral reflectance

Spectral reflectance shows which parts of the visible spectrum are absorbed or reflected by the object. There is a certain relationship between the shape of the reflectance curve and the visual characteristics of the object [15]. The reflectance measured by the DigiEye and the spectrophotometer is reported for the wavelength range of 400–700 nm at an interval of 10 nm. Fig. 6 presents spectral reflectance for sample T1 (white fabric). There is a significant difference in the reflectance measured by the two instruments in the 400–480 nm range, while at wavelengths over 490 nm the results are almost identical (Fig. 6).

Fig. 4. Placement of a fabric sample in the lightened cabinet

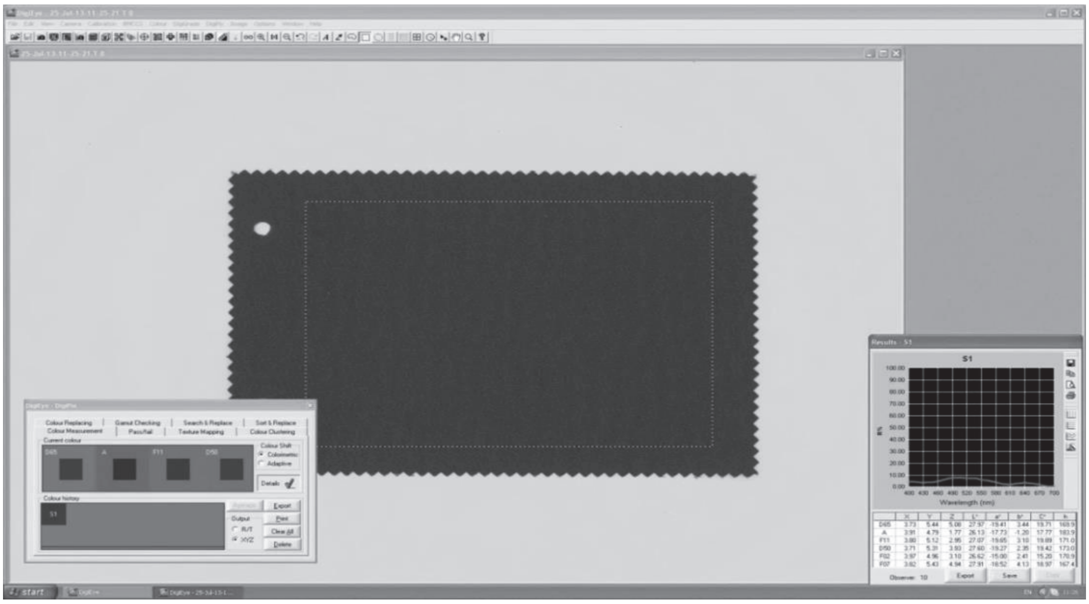

Fig. 5. Selection of a measurement area from the sample image using the rectangle tool.

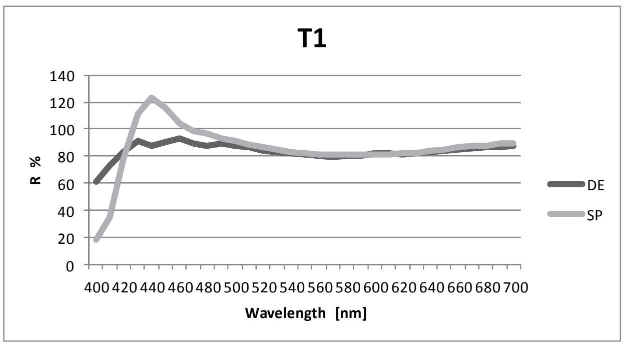

Fig. 6. Comparison of spectral reflectance determined by the DigiEye and the spectrophotometer for sample T1

As can be seen from Fig. 6, the DigiEye colorimeter does not respond to optical brighteners. Those substances exhibit fluorescence, i.e., they absorb radiation in the near ultraviolet range, moving into an excited state. Subsequently, optical brightener molecules return to the ground state by emitting excess energy in the form of electromagnetic radiation of a longer wavelength. This means that optical brighteners emit radiation in the visible spectrum corresponding to a violet-blue colour. In the case of optical brighteners on textile products, the bluish fluorescence radiation adds to the radiation reflected from the surface of the fabric, making the colours of the fabric more vibrant. Re-emission in the wavelength range 400-470 nm may exceed 100%.

The opposite is true for the black fabric (sample T10, Fig. 7). Here, differences occur towards the end of the spectrum, within the 670–700 nm wavelength range, while in the 400–660 nm range the results obtained from both instrument are identical.

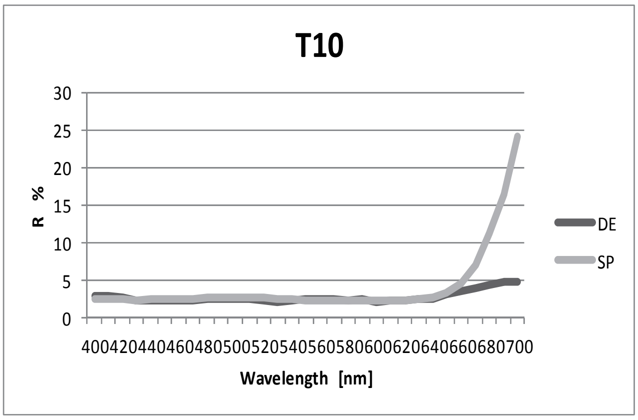

Fig. 7. Comparison of spectral reflectance determined by the DigiEye and the spectrophotometer for sample T10

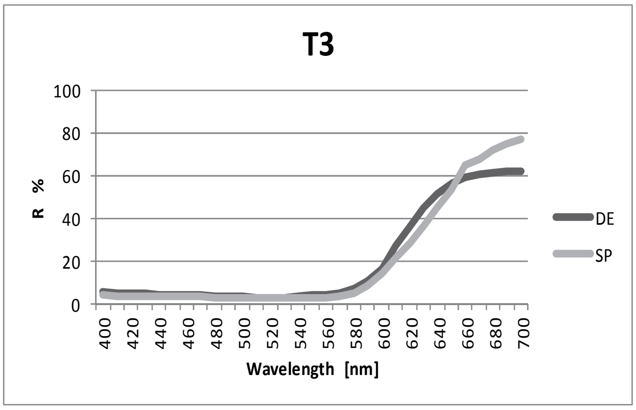

Fig. 8. Comparison of spectral reflectance determined by the DigiEye and the spectrophotometer for the sample T3

A similar pattern, with spectral reflectance discrepancies at a wavelength of 670 nm and longer, is found for the other samples (Fig. 8) with the exception of sample T5 (Fig. 9). In the latter case, the reflectance determined by the DigiEye for the khaki fabric is higher than that measured by the spectrophotometer across the entire spectrum.

The aforementioned differences in the spectral curves plotted from the spectrophotometer and DigiEye readings contribute to differences in the values of the colour coordinates, discussed in the next chapter. Taking into consideration the importance of spectral reflectance distribution for the visual perception of fabrics, it is necessary to further investigate the relationship between the reflectance determined by the DigiEye and spectrophotometer as well as analyse the repeatability of reflectance results from the two instruments.

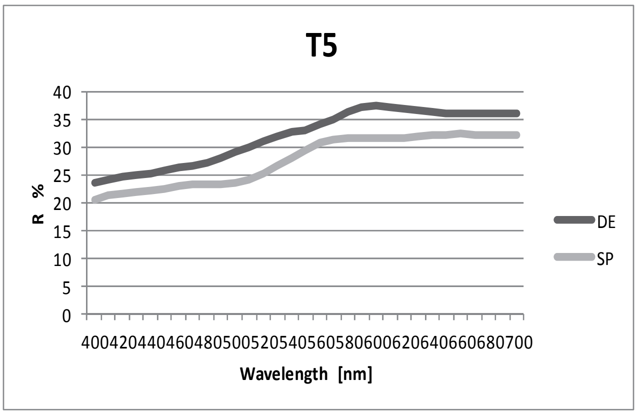

Fig. 9. Comparison of spectral reflectance determined by the DigiEye and the spectrophotometer for sample T5

3.2. Colour coordinates

Figures 10–14 show a comparison of the colour coordinates obtained by means of the two instruments. It can be seen that the values of all colour parameters measured by the DigiEye are very similar to those determined by the spectrophotometer. As expected, the highest lightness was obtained for sample T1 (white fabric), at 93.03 and 93.91 for the Digi Eye and the spectrophotometer, respectively (Fig. 10), while the lowest *L** values were found for the T10 sample (black fabric). In the majority of cases (7 fabrics), the lightness results from the spectrophotometer were slightly higher than those from the DigiEye.

A similar relationship between DigiEye and spectrophotometer results was obtained for the *a** chromaticity coordinate (Fig. 11).

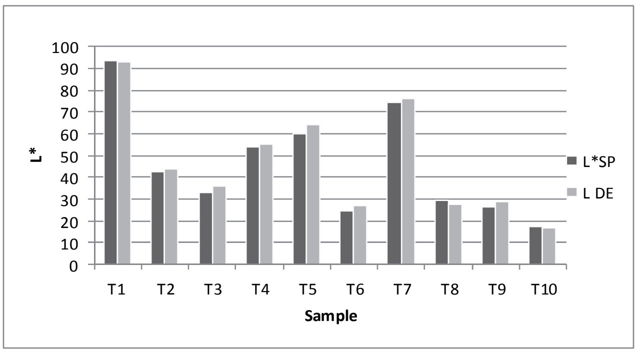

Fig. 10. Comparison of lightness (L) results from the DigiEye (DE) and the spectrophotometer (SP)

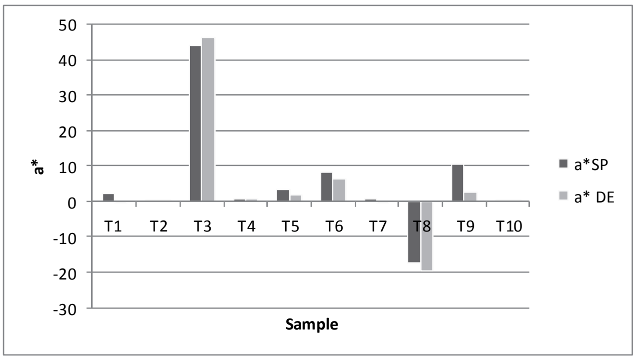

Fig. 11. Comparison of a* chromaticity coordinate results from the DigiEye (DE) and the spectrophotometer (SP)

In the case of the T1 sample (white fabric), marked discrepancies were found for the *b** and *C** chromaticity coordinates. On the other hand, for the T10 sample (black fabric), there was a major divergence in the *h* parameter (hue angle) as ascertained by the DigiEye and the spectrophotometer. It is difficult to explain these differences, which are generally rather small. It should be noted that there are no standardized procedures of fabric colour measurement by means of the DigiEye. For the presented study, we developed a procedure after preliminary measurements. The size of measurement area was chosen according to the sample size to cover the central part of the sample area and to avoid the edges. In the future, it will be necessary to elaborate a detailed procedure for measuring textile materials with the DigiEye, especially for printed fabrics or fabrics manufactured from coloured yarns.

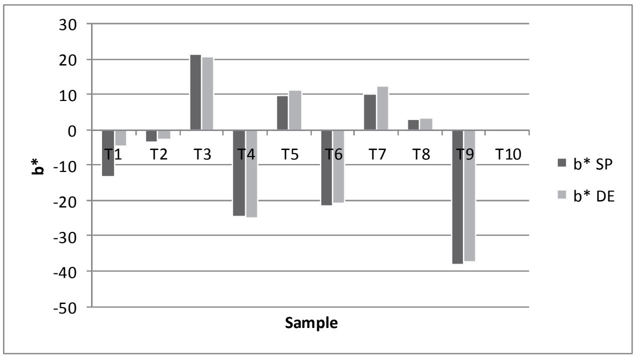

Fig. 12. Comparison of b* chromaticity coordinate results from the DigiEye (DE) and the spectrophotometer (SP)

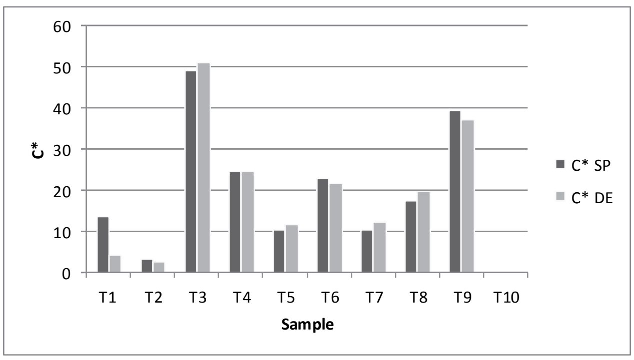

Fig. 13. Comparison of C* chromaticity coordinate results from the DigiEye (DE) and the spectrophotometer (SP)

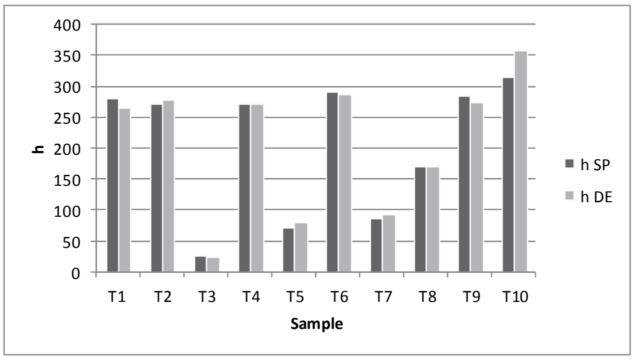

Fig. 14. Comparison of hue angle (h) results from the DigiEye (DE) and the spectrophotometer (SP)

On the basis of the presented results, the linear correlation coefficients (Person's R) were calculated according to the following equation:

$$R_{x,y} = \frac{\text{cov}(x,y)}{SD_x SD_y} \quad (2)$$

where:

SD_x – standard deviation of X variable,

SD_y – standard deviation of Y variable,

cov(x, y) – covariance expressed by the equation:

$$\text{cov}(x,y) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{n} \quad (3)$$

x_i, y_i – consecutive pairs of values of X and Y variables,

$\bar{x}$, $\bar{y}$ – average values of X and Y variables,

n – number of observation pairs.

Performed analysis confirmed a statistically significant and very strong correlation between the values of colour parameters determined by the DigiEye and the spectrophotometer. Correlation coefficients for the results from the two instruments are presented in Table 2.

Table 2. Correlation coefficients between the results from the DigiEye and the spectrophotometer

Colour parameter	Correlation coefficient $R_{x,y}$
*L**	0.9971
*a**	0.9878
*b**	0.9888
*C**	0.9782
*h**	0.9787

However, it should be noted that in colour measurement correlation coefficients between colour parameters are not of primary importance. To evaluate the degree of agreement between two methods or instruments, it is necessary to analyse absolute differences between the values of colour parameters.

3.3. Colour differences

One of the most important aspects of textile quality assessment is determination of colour differences. In textile practice, these differences are typically evaluated during the approval of textile materials for production or during the quality control of yarns, fabrics, and garments upon their delivery. Colour differences are also assessed during the measurement of colour fastness of textiles. In this case, colour changes are evaluated subjectively by visual comparison under standard lighting conditions.

From the point of view of appropriate selection of fabrics for the manufacture of a garment with the required colouring, it is important to accurately and quantitatively assess colour differences, which can be calculated on the basis of results from colour coordinate measurements according to the following formula [5]:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (4)$$

where:

ΔE – colour difference according to the CIE recommendation,

ΔL – lightness difference,

Δa – *a** chromaticity coordinate difference,

Δb – *b** chromaticity coordinate difference.

The above equation is optimized for accuracy in determining the colour difference between similar colours (Δ*E* of about 1 unit) to facilitate pass/fail decisions. Usually, in the clothing industry practice, colour differences are evaluated for samples which should be of the same colour, e.g., during colour matching and approval of fabrics for the manufacture of a garment of a required colour. In such cases, the colour differences between the measured and batch samples tend to be very small.

The analysed samples represent different colours as the investigated fabrics were selected to ensure a wide colour range. As a result, colour differences between them are large, of the order of more than ten units, and so they cannot be used to evaluate the degree of agreement between the two instruments.

Therefore, further research is necessary to establish agreement between the spectrophotometer and DigiEye in terms of colour difference determination. This should be done on the basis of measurements of fabric samples of identical or similar colours.

4. SUMMARY

The study revealed certain differences in the shape of spectral reflectance curves between the DigiEye and the spectrophotometer in some regions of the spectrum, which influenced the measured values of the colour coordinates. A strong correlation was found between the coordinate measurement results obtained by means of the two instruments, with the lightness and chromaticity coordinates being almost identical. There was also a strong correlation between the colour differences calculated on the basis of the results obtained from the DigiEye and the spectrophotometer. However, as correlation coefficients between the various colour parameters are not of primary importance in colour measurement, further research should be conducted to assess the degree of agreement between the spectrophotometer and DigiEye in terms of colour difference determination.

REFERENCES

1. Z. Khatri, G. Y. Sheikh, K. M. Brohi, A. A. Uqaili, Effective Colour Management for Textile Coloration- An instrumental way towards perfection, Proceedings of the 2011 International Conference on Industrial Engineering and Operations Management, Kuala Lumpur, Malaysia, 2011, pp. 1073–1079.
2. Nussbaum P., Colour Measurement and Print Quality Assessment in a Colour Managed Printing Workflow, Doctoral Dissertation, Department of Informatics University of Oslo, Norway, 2010.
3. Fan J., Lau L., Hunter L., Appearance issues in garment processing, chapter in: Engineering apparel fabrics and garments, edited by Fan J., Hunter L., Woodhead Publishing Limited 2009, pp. 131–160.
4. Anderson K., Selecting the Correct Sewing Thread, 2009 available at: www. texexchange.com>.
5. Matusiak M., Walawska A., Important Aspects of Cotton Colour Measurement, FIBRES & TEXTILES in Eastern Europe 2010, Vol. 18, No. 3 (80) pp. 17–23.
6. Ngo L. L., Colour matching system for colour approval of multi-component apparel, The Hong Kong Polytechnic University, 2012, available in: www.lib.polyu.edu.hk on 16.02.2015.
7. Cheng L., Ghorashi H., Duckett K., Zapletalova T. Watson M. D., Colour Grading of Cotton. Part II: Colour Grading with an Expert System and Neural Networks, Textile Research Journal 69 (12), 1999, pp. 893 - 903.
8. Adamczyk P., Rutowicz J., Frydrych I., Comparative Analysis of Results Obtained from Devices: Macbeth & DigiEye, International Conference STRUTEX'2012, Liberec Czech Republic, 2012.
9. Berns S. R., Billmeyer and Saltzman's principles of colour technology (3rd edition) New York, 2000, A Wiley – Interscience.
10. DigiEye User Guide Version 2.51, VeriVide Ltd., 2010.
11. Matusiak M., DigiEye Application in Cotton Colour Measurement, Autex Research Journal 1 (2015), (accepted).
12. Lau L. N., Kan C. W., Yuen Marcus C. W., Lau Robert K. W., Study of the Correlation between Solid Colors Measured by Spectrophotometer and DigiEye, The First International Conference on Interdisciplinary Research and Development, 31 May - 1 June 2011, Thailand.
13. Colour measurement. Patterns & prints, Information brochure of VeriVide Limited, available at: < http://www.verivide.com> on 17.02.2015.
14. Yaoyuneyong G., Effects of Illuminants and Retail Environments on Colour of Textile Fabrics, Ph.D. thesis, College of Human Sciences of The Florida State University, 2007.
15. Hirschler R., Electronic colour communication in the textile and apparel industry, REDIGE Vol. 1. No. 1, 2010, pp. 43–61.