Quality Assurance in Textile Industry using a Fiber-Optic Spectroscopy Sensor

Olga M. Conde, Ana M. Cubillas, Pedro Anuarbe, Jose M. Lopez-Higuera
Photonics Engineering Group, University of Cantabria, Santander, Spain
olga.conde@unican.es

Abstract: An extrinsic optical fiber sensor method for color matching assessment of textile dyes using their Ultraviolet-Visible-Near Infrared (UV-Vis-NIR) transmission spectra is proposed in this paper. Spectra values are converted to CIELAB coordinates to improve the calculation of color differences. Color matching assessment is finally performed using Receiver Operating Characteristic (ROC) curves to find the optimum discrimination threshold between different dye samples.

O**CIS codes:** (300.1030) Absorption; (330.6180) Spectral discrimination

1. Introduction

Textile industry is very sensitive to color appearance of fabrics and, for that reason, color matching assessment is required in textile dyeing processes. If the color produced in the dyebath is different from the color specified in the dyeing recipe, the manufactured goods have to be reworked or rejected [1]. This results in additional manufacturing costs and increased dumping of toxic wastes into the environment. Thus, a method to assess that the color of the dyebath is the same as the color of the dyeing recipe could be advantageous in textile industry.

Optical fiber spectroscopy is a very well suited technique for online monitoring the absorption and transmission spectra of dyes. This technique has many advantages such as its simplicity and ease of operation, efficiency, high-performance and relatively low cost [2]. Optical fiber spectroscopy experiments have been previously reported for olive oil, lubricant oil and beer [3]. Furthermore, in the textile industry, the concentration of dyes has been assessed using reflectance spectroscopy [4] or by monitoring the dyebath at a single spectral value [5].

The color of a dye sample is characterized by its absorption/transmission spectrum in the visible region. This spectral information can be converted to CIELAB coordinates [6] to enhance the calculation of small color differences. In this work, we present a method to assess the color matching of dye samples based on a fiber optic sensor to obtain the CIELAB coordinates and the selection of the optimum discriminant threshold using ROC (Receiver Operating Characteristic) curves [7].

2. Spectra measurement

Different samples of industrial textile dyes were placed inside a cuvette holder in disposable plastic cuvettes of 0.5 cm path light. The measurement set-up previously described in [8] has been employed to obtain the transmission and absorption spectra of the different dyes. Due to the sensitivity of the spectrometer employed in the set-up, the spectral absorbance of the samples needs to be limited to 2 AU (AU, Absorbance Units). Textile dyes, as used in the dyeing process, are thick and optically opaque, so they need to be diluted to allow the comparison between dyes. To satisfy the sensitivity limitation of 2 AU, an Optimum Dilution Factor (ODF) for each mixture needs to be calculated. This ODF is estimated as the dilution needed so that the total absorbance of the mixture is below the absorption limit of the system [8]:

$$ODF = \frac{\max(A_t)}{2} \tag{1}$$

with A_t the total absorbance of the mixture obtained from the individual absorption contributions of each dye colorant.

3. Color matching procedure

Once the transmission spectrum is acquired, the *XYZ* coordinates (CIE tristimulus values) of the dye can be computed [9]:

$$X = k\sum_{\lambda}\phi_{\lambda}(\lambda)\bar{x}(\lambda)\Delta\lambda \qquad Y = k\sum_{\lambda}\phi_{\lambda}(\lambda)\bar{y}(\lambda)\Delta\lambda \qquad Z = k\sum_{\lambda}\phi_{\lambda}(\lambda)\bar{z}(\lambda)\Delta\lambda \tag{2}$$

where $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$ are the color matching functions; $\Delta\lambda$ is the λ-step in the summation; $\phi_{\lambda}(\lambda)$ is the color stimulus function calculated as a function of the dye spectral transmittance, $T(\lambda)$, and the spectral distribution of the illuminant relative power S_λ: $\phi_\lambda(\lambda)=T(\lambda)S_\lambda(\lambda)$; k is a constant that fixes Y=100 for dyes with $T(\lambda)=1$. In order to obtain the CIELAB coordinates from the XYZ values, the following transformation is performed [9]:

$$X^* = \sqrt[3]{\frac{X}{X_n}};\quad Y^* = \sqrt[3]{\frac{Y}{Y_n}};\quad Z^* = \sqrt[3]{\frac{Z}{Z_n}} \tag{3}$$

where X_n, Y_n and Z_n are the CIE triestimulus values for the illuminant used (type E). The CIELAB coordinates $\left(L^*, a^*, b^*\right)$ can be calculated as:

$$a^* = 500\left(X^* - Y^*\right);\quad b^* = 200\left(Y^* - Z^*\right);\quad L^* = 116Y^* - 16 \tag{4}$$

As a result, each dye spectrum is transformed into a set of three values $\left(L^*, a^*, b^*\right)$, the CIELAB coordinates. The color difference between dyes can be measured using the Euclidean distance between the CIELAB coordinates:

$$D_{euclidean} = \sqrt{\left(L_1^* - L_2^*\right)^2 + \left(a_1^* - a_2^*\right)^2 + \left(b_1^* - b_2^*\right)^2} \tag{5}$$

4. Color matching results

In order to assess the performance of the method, 410 spectrum measurements over a range of 300 dye samples were obtained. Furthermore, ROC curves were employed to determine the optimum threshold distance to determine if two dye samples were equal or needed to be rejected. ROC curves are usually employed in decision making to evaluate the cost/benefit of each threshold [7]. Thus, the ROC curve is a graphical plot of the sensitivity versus the specificity as the discrimination threshold, $D_{euclidean}$, is varied. In our case, 12.880 dye combinations were evaluated to obtain the ROC curve shown in Fig.1. According to this, the optimum threshold for dye discrimination is $D_{euclidean}$=5,5 with an area under the curve (AUC) value of 0,9827, close to the ideal value of 1.

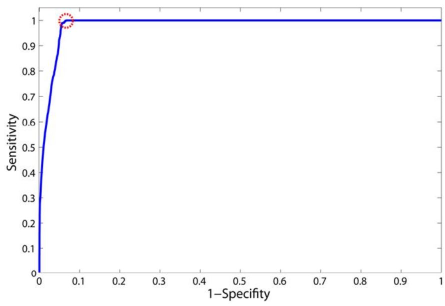

Fig. 1. ROC curve with the point of optimum operation point.

5. Conclusions

In this paper, an optical fiber spectroscopy sensor system for the online monitoring of dyes with application to the textile industry was demonstrated. ROC curves were used to obtain the optimum operation point of the system to evaluate the color matching between the dyebath and the dyeing recipe. The proposed procedure is based on the extraction of the CIELAB coordinates from the transmission spectrum of the dyes. The similarity between dyes is evaluated through the calculation of the Euclidean distance between the CIELAB coordinates. The area under the curve (AUC) obtained with this matching method was 0,9827 when an optimum threshold of 5,5 is considered.

Acknowledgements

This work has been supported by CYCIT project TEC2007-67987-C02-01, funded by the Spanish Government, and HyperTINTEX project, co-funded by Textil Santanderina S.A. and the Regional Government of Cantabria.

6. References

[1] M.Senthilkumar, "Modelling of CIELAB values in vinyl sulphone dye application using feed-forward neural networks," Dyes Pigm., **75**, 356-361 (2007).
[2] D.A.Burns, E.W.Ciurczak, *Handbook of Near-Infrared Analysis*, Third Edition. (CRC press, 2008).
[3] A.G.Mignani, L.Ciaccheri, N.Diaz-Herrera, A.A.Mencaglia, H.Ottevaere, H.Thienpont, S.Francalanci, A. Paccagnini, F.S.Pavone, "Optical fibre spectroscopy for measuring quality indicators of lubricant oils," Meas. Sci. Technol. **20**, 034011-1-7 (2009).
[4] M.Blanco, T.Canals, J.Coello, J.Gené, H.Iturriaga, S.Maspoch, "Direct determination of leather dyes by visible reflectance spectroscopy using partial least-squares regression," Anal. Chim. Acta, **419**, 209-214 (2000).
[5] U.Sahin, A.Ülgen, A.Kekeç, A.Gökmen, "Real-time monitoring of indigo concentrations in the dyebath with a laser diode spectrometer," Text. Res. J., **74**, 193-197 (2004).
[6] Commission Internationale de l'Eclairage, Colorimetry, 2nd edition, CIE: Vienna, Austria (1986).
[7] T. Fawcett, " An introduction to ROC analysis," Pattern Recognition Letters **27**, 861–874 (2006).
[8] O.M.Conde, A.M.Cubillas, P.Anuarbe, J.M. Lopez-Higuera, M.Gutierrez, V.Martinez, "Fiber-optic spectroscopic sensor for reactive dye mixture spectrum synthesis in textile industry," IEEE Sensors 2009, (Institute of Electrical and Electronics Engineers, 2009), pp. 136-139.
[9] H.G.Völz, *Industrial Color Testing*, 2nd Edition. (Wiley InterScience, 2003).