The colorimetric measurement of mélange woollen yarns: a new optical tool

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The Colorimetric Measurement of Mélange Woollen Yarns: A New Optical Tool

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Abstract: One of the most critical phases of the production of woollen yarns for knitting and weaving is the comparison between the colour of the finished product and the colour desired by a customer or provided by a catalogue. Accordingly the companies that produce yarns perform a colorimetric control of their products by evaluating the colorimetric distance between the final product, obtained by mixing the coloured raw material and the desired one. This colorimetric control is mainly performed using a calibrated reflectance spectrophotometer thus allowing an accurate measurement of the spectrum of a woollen yarn. This is performed only in the case of uniform colour. Being the area of the spectrophotometer acquisition sensor very small (20 mm^2) when a woollen yarn is composed by two or more colours (i.e., is a mélange woollen yarn) the spectrophotometer is not able to discriminate all the colours reliably. The objective of the present research, developed by the Dipartimento di Meccanica e Tecnologie Industriali of the University of Florence in collaboration with the company Newmill S.p.A., is to develop an optical system (tool) able to perform an accurate colorimetric measurement of melànge woollen yarns on the basis of the combination of flat scanner acquisition and colorimetric techniques.

Key words: Yarns, spectrophotometry, optical colorimetry, CIELAB, CIELCH

INTRODUCTION

The common practice for companies that produce yarns of desired colours (provided by a catalogue or by a customer) is to mix some coloured fibres by means of some recipes. Depending upon the customer's choice or the desired colour by the catalogue, the companies start to search their storehouse for correctly coloured fibres and then mix them by means of a machine called carder. By means of the carder the company create a cloth that have to be compared with the one used as reference. The dye process does not allows a reliable reproduction of the colour demanded for the raw materials composing the cloth. Accordingly, using a particular recipe for creating the cloth, the result may be very different, in terms of colour, from the reference. As a consequence the companies have to perform a colorimetric comparison between the reference cloth and the one obtained by using a recipe. The colour of the cloths is considered to be the colour of the yarn. Accordingly in the following pages the term cloth is used for indicating the product of a carder operation of coloured fibres. This is normally obtained by means of a spectrophotometric measurement of these cloths. As widely known (Lee and Powers, 2005) the colorimetric differences between two coloured cloths may be conventionally performed by means of colorimetric equations able to evaluate the CIELAB and the CIELCH distances. These distances are mainly used in the textile field (Bartolini and Brachi, 2002) and have to be evaluated under the following standard illuminants (Leon *et al*., 2006):

- D65: Corresponds roughly to a midday sun in Western/Northern Europe with a U.V. spectrum component and a colour temperature of 6500K.
- A: Used to represent incandescent lighting such as a filament lamp at 2856K.
- TL84: Mathematical representation of commercial, narrow band fluorescent used in the USA with a colour temperature of 4000K.
- F2: Mathematical representation of commercial, wide band fluorescent used in the USA (Cool White Fluorescent) at the colour temperature of 4150K.

When a cloth is composed by fibres of very different colours, (in this case the cloth is called mélange) the spectrophotometer measurement may be affected by some technological limitations originated by the small area of the acquisition sensor. For instance, if we consider a cloth composed by two kinds of fibres, one red and the other green, acquiring an area of 20 mm^2 of the cloth the spectrophotometer may not discern the spectra of the 2

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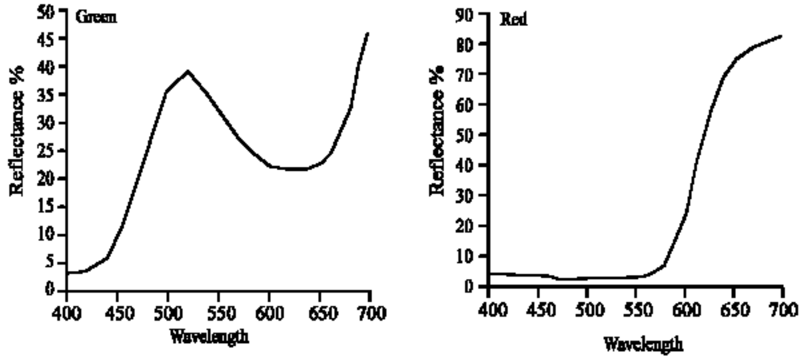

Fig. 1: Two spectra of the same red-green cloth acquired in 2 different positions

colours. In Fig. 1 the acquisition of the same red-green mélange cloth in 2 different positions is shown. The presence of relevant differences in these spectra shows as the spectrophotometric measurement is not suitable to perform the comparison between two mélange cloths.

Objectives of the study: The main objective of the present research, developed by the Dipartimento di Meccanica e Tecnologie Industriali of the University of Florence in collaboration with the company Newmill S.p.A., has been the development of an optical colour measurement tool (hardware+software) able to perform a reliable colorimetric measurement of melànge cloths in order to correctly evaluate the CIELAB and CIELCH distances between a cloth obtained with a carder and the one considered as reference. The developed tool overcomes the limitations imposed by the spectrophotometric approach since it is able to compare also cloths composed by 2 or more differently coloured fibres. Accordingly the devised tool is able to give relevant information to the technicians about some objective characteristics of the cloth like, for instance, hue, saturation, red/blue dominance and yellow/green dominance. The system is able to perform a measurement of both the reference and the carded cloth in a large area (10 cm^2) thus allowing a more accurate measurement. Moreover the system provides repeatable measurements and exhibits a low evaluation error.

The objectives of the research have been reached by means of the following tasks:

- Hardware development and image processing
- Colour conversion from RGB to CIELCH
- Evaluation of CMC distance
- Development of the colour tool software

HARDWARE DEVELOPMENT AND IMAGE PROCESSING

The devised colour measurement tool system comprises of a commercial flat scanner Epson Perfection

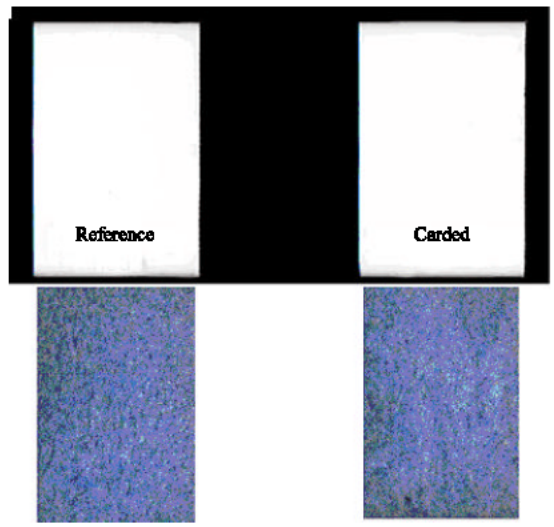

Fig. 2: Mask used for the comparison between 2 coloured cloths

4490 Photo, with a 42 bit colour depth, a resolution of 4800×9600 dpi and a white cold cathode fluorescent lamp. The white calibration of the acquisition system is performed at the beginning of data acquisition using a Epson standard cap. The scanner is connected to a PC by means of an Graphical User Interface (GUI) appositely developed in Matlab® environment. The acquisition is performed by using an ActiveX Twain controller. A devised colorimetric measurement software, installed in the PC, evaluate the CIELAB and the CIELCH distances starting from the RGB images acquired with the hardware system. In order to carry out the colour measurement, the technicians have to put the reference cloth and the carded one into the mask of Fig. 2.

An appositely developed software performs an automatic scanning of the image and crop it into two 48 bit RGB images with a resolution of 600 ppi and a dimension of 100 cm^2 (i.e., about 500 times larger than the spectrophotometer sensor area): The acquired image of the reference cloth and the one acquired for the carded cloth. The spatial resolution of the acquired images is 0.03 $mm^2/pixel^2$. Due to the large acquisition area, the comparison between the two cloths may be translated in the comparison between the mean values of R, G and B values of the images without regard to the number or the kind of colour used for carding the cloths themselves. So the first operation carried out by the software is the evaluation of the mean values R_R G_R and B_R for the image of the reference cloth and the mean values R_C G_C and B_C for the image of the carded cloth.

COLOUR CONVERSION FROM RGB TO CIELCH

By means of the wide know Eq. 1 it is possible to convert the colour space from the RGB space to the tristimulus values CIE XYZ (Kim and Nobbs, 1997), under the illuminant D65, for the reference and for the carded cloth:

$$\begin{cases}[X_{D65}, Y_{D65}, Z_{D65}]_R = [R,G,B]_R \cdot M_{D65} \\ [X_{D65}, Y_{D65}, Z_{D65}]_C = [R,G,B]_C \cdot M_{D65}\end{cases} \quad (1)$$

Where the matrix M_{D65} (size 3×3) is given by the following equation:

$$M_{D65} = \begin{bmatrix} 0.57670000 & 0.29736100 & 0.02703280 \\ 0.18555560 & 0.62735500 & 0.00706879 \\ 0.18821200 & 0.07528470 & 0.99124800 \end{bmatrix} \quad (2)$$

The problem is that the colorimetric control have to be assessed also under the illuminants A, TL84 and D65. Accordingly a chromatic adaptation algorithm have to be implemented in order to carry out a linear transformation of the source colour (X_{D65}, Y_{D65}, Z_{D65}) into, respectively, the destination colours (X_A, Y_A, Z_A), (X_{F2}, Y_{F2} Z_{F2}) and (X_{TL84}, Y_{TL84} Z_{TL84}) by some linear transformations which are dependent on the source reference white $(X_{D65_0}, Y_{D65_0}, Z_{D65_0})$, the destination reference white $(X_{A_0}, Y_{A_0}, Y_{A_0})$, $(X_{F2_0}, Y_{F2_0}, Z_{F2_0})$ and $(X_{TL84_0}, Y_{TL84_0}, Y_{TL84_0})$. The linear transformation is given by three matrices $M_{D65\text{-}A}$, $M_{D65\text{-}F}$, $M_{D65\text{-}TL84}$ according to the following equations:

$$\begin{cases}[X_A, Y_A, Z_A] = [X_{D65}, Y_{D65}, Z_{D65}] \cdot M_{D65-A} \\ [X_{F2}, Y_{F2}, Z_{F2}] = [X_{D65}, Y_{D65}, Z_{D65}] \cdot M_{D65-F2} \\ [X_{TL84}, Y_{TL84}, Z_{TL84}] = [X_{D65}, Y_{D65}, Z_{D65}] \cdot M_{D65-TL84}\end{cases} \quad (3)$$

The matrices $M_{D65\text{-}A}$, $M_{D65\text{-}F}$ $M_{D65\text{-}TL84}$ are evaluated with the Von Kries method (Fairchild, 1996).

Finally the conversion between the 48 bit RGB and the LABXYZ colour spaces is obtained as follows:

$$\begin{cases}[X_A, Y_A, Z_A]_R = ([R,G,B]_R \cdot M) \cdot M_{D65-A} \\ [X_{F2}, Y_{F2}, Z_{F2}]_R = ([R,G,B]_R \cdot M) \cdot M_{D65-F2} \\ [X_{TL84}, Y_{TL84}, Z_{TL84}]_R = ([R,G,B]_R \cdot M) \cdot M_{D65-TL84} \\ [X_A, Y_A, Z_A]_C = ([R,G,B]_C \cdot M) \cdot M_{D65-A} \\ [X_{F2}, Y_{F2}, Z_{F2}]_C = ([R,G,B]_C \cdot M) \cdot M_{D65-F2} \\ [X_{TL84}, Y_{TL84}, Z_{TL84}]_C = ([R,G,B]_C \cdot M) \cdot M_{D65-TL84}\end{cases} \quad (4)$$

The knowledge of the XYZ values for the reference and for the carded cloths, allows the colour transformation in the CIELAB space simply using the XYZ to CIELAB relations (Williams, 2006) for each of the reference white calibrated for the different kind of illuminants described in section 1. In other words, it is possible to evaluate the values L_R, a_R and b_R for the image of the reference cloth L_c, a_c and b_c for the image of the carded one. Finally it is possible to convert the CIELAB space in the CIELCH space that is the most used for assessing colorimetric measurement in textile field (Gonnet, 1998):

$$\begin{cases}L_R = L_R \\ C_R = \sqrt{{a_R}^2 + {b_R}^2} \\ H_R = \tan^{-1}(b_R / a_R) \\ L_C = L_C \\ C_C = \sqrt{{a_C}^2 + {b_C}^2} \\ H_C = \tan^{-1}(b_C / a_C)\end{cases} \quad (5)$$

Furthermore the colorimetric differences between the two images (i.e., the differences between the two cloths) may be expressed like the delta between L, C and H values:

$$\begin{aligned}\Delta L &= L_C - L_R \\ \Delta C &= L_C - L_R \\ \Delta H &= L_C - L_R\end{aligned} \quad (6)$$

Evaluation of CMC distance: In the textile field, normally, the colorimetric difference between the carded cloth and the reference is very small. So a Britain standard is used for measure small colorimetric distances. This standard allows the evaluation of a difference called CMC distance whose equation is the following:

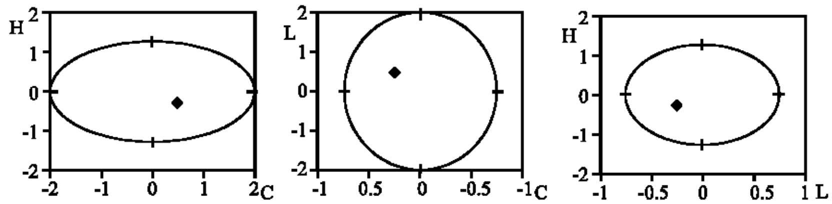

Fig. 3: Sections of the CMC ellipsoid with the planes HC, LC and HL under the D65 illuminant

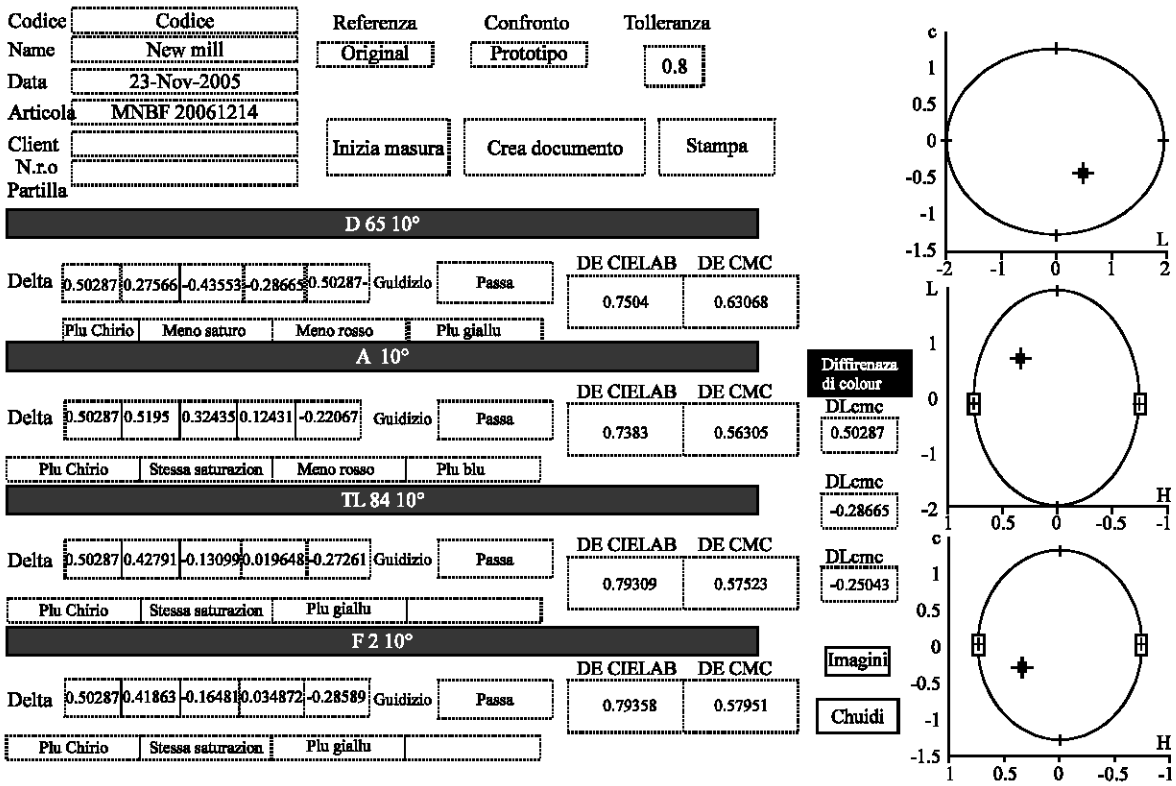

Fig. 4: GUI developed in order to guide the technicians in the color measuremen

$$\begin{aligned}
DE_{CMC_{D65}} &= \sqrt{\left(\frac{\Delta L_{D65}}{(lS_L)_{D65}}\right)^2 + \left(\frac{\Delta C_{D65}}{(cS_C)_{D65}}\right)^2 + \left(\frac{\Delta H_{D65}}{(S_H)_{D65}}\right)^2} \\
DE_{CMC_A} &= \sqrt{\left(\frac{\Delta L_A}{(lS_L)_A}\right)^2 + \left(\frac{\Delta C_A}{(cS_C)_A}\right)^2 + \left(\frac{\Delta H_A}{(S_H)_A}\right)^2} \\
DE_{CMC_{F2}} &= \sqrt{\left(\frac{\Delta L_{F2}}{(lS_L)_{F2}}\right)^2 + \left(\frac{\Delta C_{F2}}{(cS_C)_{F2}}\right)^2 + \left(\frac{\Delta H_{F2}}{(S_H)_{F2}}\right)^2} \\
DE_{CMC_{TL84}} &= \sqrt{\left(\frac{\Delta L_{TL84}}{(lS_L)_{TL84}}\right)^2 + \left(\frac{\Delta C_{TL84}}{(cS_C)_{TL84}}\right)^2 + \left(\frac{\Delta H_{TL84}}{(S_H)_{TL84}}\right)^2}
\end{aligned} \qquad (7)$$

CMC is not a colour space but rather a tolerancing system. CMC tolerancing is based on CIELCH and provides better agreement between visual assessment and measured colour difference. CMC tolerancing was developed by the Colour Measurement Committee of the Society of Dyers and Colourists in Great Britain and became public domain in 1988 (Syed *et al*., 1996).

The CMC calculation mathematically defines an ellipsoid around the standard colour with semi-axis lS_L, cS_C and S_H corresponding to lightness, chroma and hue. The ellipsoid represents the volume of acceptable colour and automatically varies in size and shape depending on the position of the colour in colour space. The section of the ellipsoid with, respectively, the planes HC, LC and HL, allows the detection of the limits of acceptable colours with respect to the reference. In Fig. 3 these 3 sections are showed for a carded cloth whose colour is very similar to the reference one.

SOFTWARE DEVELOPMENT

When a carded cloth have to be compared with a reference, the technicians put them into the scanner and the devised tool automatically scan the cloths and evaluate the CIELCH colour coordinates for each acquired image. The textile company have only to state the maximum accepted value for the distance DE_{CMC} and the developed software is able to represent in three 2D ellipses if the cloth to be compared with the reference is acceptable. In Fig. 4 is showed the GUI developed to guide the company technicians to the results of the colorimetric comparison. The GUI allows a direct comparison from the reference cloth and the carded one giving relevant information about both the CMC and the CIELAB distances under the illuminants (the ones used for textile colour assessment). Furthermore it indicates some qualitative information useful to help the technicians i.e., the differences in saturation, or in the luminance. This is possible thanks to a purposely developed algorithm able to evaluate and ΔL, Δa, Δb, ΔR, ΔG, ΔB, ΔH and ΔC for both the cloths compared.

CONCLUSION

The measurement system has been tested with more than 300 differently uniformly coloured cloths by means of the new optical approach in parallel with the spectrophotometric one. The error in the measurement of CMC distance, i.e., the absolute difference between the spectrophotometric measurement and the new optical one, is smaller than 5%. So the new developed system allows a reliable measurement, useful for the company intent. Moreover the new optical measurement have been proved to be accurate in the case of melange cloths where the spectrophotometer approach lead to a lack of reliability.

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