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A Vision-Based Method for the Assessment of Colour Fastness to Washing

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Abstract**:** ***Colour fastness is a major factor governing the durability and acceptability of a textile-based product. The most common prevalent method for assessing colour fastness is by means of manual rating using grey scales. This process is subjective, and the rating may depend on the skill and experience of the assessor. While digital methods are available they are very costly. This research aims to propose a method to rate colour fastness using a cost-effective method using image processing. Images of fabrics before and after washing were captured and then processed using a programme developed by the researchers. Based on the cie de2000 colour difference formula the delta e value between the two fabrics was calculated and the corresponding grey scale rating identified.***

Keywords: cielab colour space, colour, colour fastness, delta e, grey scale rating, vision

I. INTRODUCTION

Colour is the aspect of appearance of objects and lights which depend upon the spectral composition of the radiant energy reaching the retina of the eye and upon its temporal and spatial distribution theorem [1]. Colour is a major consideration in buying a textile product by the customer. A user of a product will be concerned with the consistency of the colour of the product as well as its durability. Colour fastness may be defined as the ability of the substrate to retain its depth of shade when exposed to particular processes or agencies. Due to washing, rubbing, exposure to light among others, the colour in a fabric may fade or bleed, causing a change in the hue, thus rendering the material unacceptable to the use. Hence colour fastness is an important property in determining the durability and acceptability of a material.

The traditional method for assessing colour fastness is using grey scales. [2]. The grey scale is used to compare the visual colour variation between the original and processed samples with standard grey colour difference, and then rate the colour difference. Here the rating is done using the naked eye by comparing colours with the use of grey scale. Use of grey scales is more time consuming and can be subjective, the results varying from one observer to another. Due to this experienced trained observers are needed to give correct readings [3]. Thus it can be seen that visual colour matching can be inconsistent and unreliable due to the subjectivity. Digital systems, such as those using a spectrophotometer are available, but at a high cost.

Instrumental colour fastness rating can be said to be more precise and less subjective than manual rating. However these are costly, and in addition, as pointed out by Zuan, Yang and Cai, may be affected by testing conditions, fabric surface, colour-difference formulae, standard illuminants, geometric conditions and field angles [4]. Spectrophotometers are used in the industry for the grading of the colour fastness according to the customer requirements. Spectral power distribution reflected by samples is measured and tristimulus values of colours under the standard illuminant used. The colour value is calculate based on colour-difference formulae and converted to a colour fastness rating. Colorimeters, on the other hand, digital imaging is used to measure the tristimulus values of a sample and calculate values in a three-value colour space that can be compared with standard values. [5]

A colour space is a method by which the observer may specify, create and visualize colour. Colour may be defined by its attributes of hue, chroma and value. There are a number of colour spaces which may be used as appropriate for the application. In this research the RGB colour space was used as camera images are captured in RGB colours. The L*a*b* colour space is used to calculate the colour difference as it includes all perceivable colours. The former is device-dependent, and the colour obtained depends on the instrument and the illuminant, as well as other factors. The L*a*b* colour space on the other hand is device-independent, and an opponent colour system based on the earlier (1942) system of Richard Hunter called L, a, b. CIELAB indicates values with three axes: L*, a*, and b* [6].

Fig. 1 graphically illustrates the CIELAB colour space. The central vertical axis represents lightness (signified as L*) whose values run from 0 (black) to 100 (white). The colour axes (a* and b*) are based on the opponent colour theory, where red and green (a*) are seen as opposites, as are blue and yellow (b*). On each "a" and "b" axis the values run from positive to negative infinity.

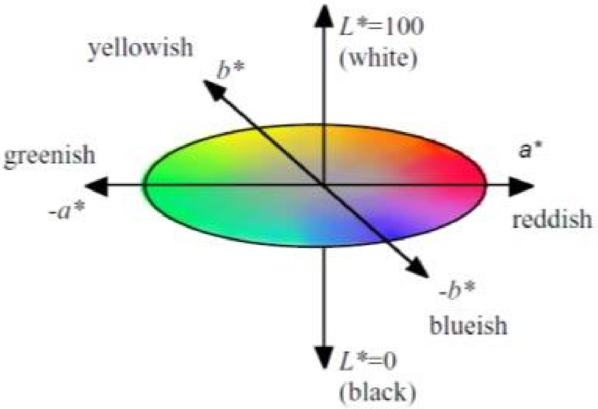

Fig. 1 CIELAB color space [7]

As different illuminants will give different RGB values it is important to use a standard illuminant. The D65 is a standard illuminant defined by CIE and widely used in the textile industry. D65 is said to correspond to the mid-day sun in Europe, and thus it is also referred to as a daylight illuminant [8]. It is this illuminant that has been used in this research.

The CIELab colour difference formula, which is used to calculate the mathematical difference between the measurements of two colours, was introduced in 1976. The original formula was:

$$\Delta L^* = L_2^* - L_1^*, \Delta a^* = a_2^* - a_1^*, \Delta b^* = b_2^* - b_1^* \qquad (1)$$

and

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

where subscript 1 is for the standard specimen and 2 for the test sample, and E*ab the total colour difference.

The CIEDE2000 colour difference formula was published in 2001. The equation of DE2000 formula is

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \qquad (3)$$

The derivation of CIEDE 2000 formula is as follows:

$$a' = (1 + G)a^*$$

$$b' = b^* \qquad (4)$$

$$C' = \sqrt{a'^2 + b'^2}$$

$$h' = tan^{-1}(b'/a')$$

Where, $G = 0.5\left(1 - \sqrt{\frac{\overline{C_{ab}^{*7}}}{\overline{C_{ab}^{*7}} + 25^7}}\right)$ (5)

Where $\overline{C_{ab}^{*7}}$ is the arithmetic mean of the ${C^*}_{ab}$ values for a pair of samples.

Here

$$S_L = 1 + \frac{0.015\,(\bar{L}'-50)^2}{\sqrt{20+(\bar{L}'-50)^2}}$$

$$S_C = 1 + 0.045\,\overline{C'} \qquad (6)$$

$$S_H = 1 + 0.015\,\overline{C'}\,T$$

Where

$$T = 1 - 0.17\cos(\bar{h}' - 30^\circ) + 24\cos(2\,\bar{h}') + 0.32\cos(3\,\bar{h}' + 6^\circ) - 0.2\cos(4\,\bar{h}' + 63^\circ) \qquad - \quad (7)$$

And

$$R_T = -\sin(2\Delta\theta)\,R_C$$

Where

$$\Delta\theta = 30\,exp\left\{-\left[\frac{\bar{h}'-275^\circ}{25}\right]^2\right\}$$

$$R_C = 2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7+25^7}} \qquad (8)$$

he above equations were as given in [9].

II. METHODOLOGY

In this research the reference and test specimens were placed in a light box under a D65 light source. Using a high definition camera the respective images were captured and cropped, after which their respective mean RGB values were calculated. These values were then converted to the Lab colour space, following which the DE2000 colour difference was calculated. Based on this difference value a gray scale rating was given.

A. *Image Capture*

A 24 megapixel Nikon D5200 camera was used for the image capture. The camera had a maximum resolution of 6000x4000, and an image width to height ratio of 3:2. Table I shows the parameters used in image capture.

TABLE I
IMAGE CAPTURE PARAMETERS

Illumination-observation conditions	45/0
Distance between fabric and sensor	70cm
Camera lens zoom	35mm
Aperture	f/8
Exposure time	1/10 s
ISO speed	100
Image format	NEF (RAW)
Image resolution	6000x4000

The apparatus used for image capture is described in Fig. 2:

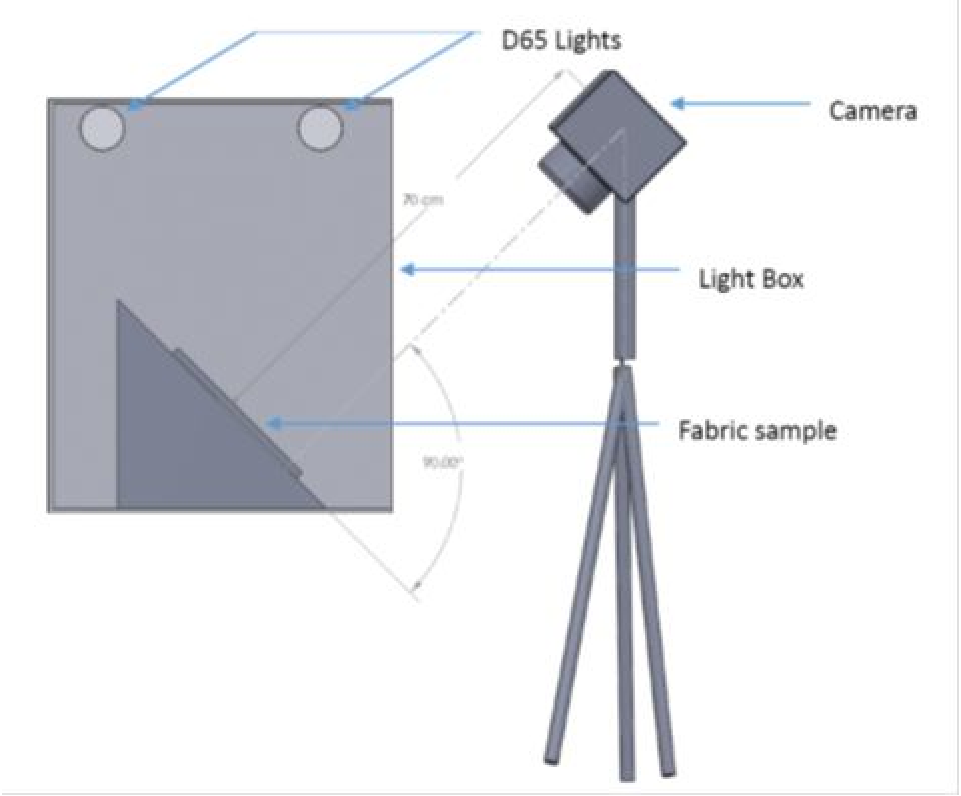

Fig. 2 Image capture arrangement

45/0 denotes that the angle between axis of illumination beams and normal line of samples, surface is 45 ± 2 ° This is similar to the setting used when assessing colour fastness in the normal manner. Fabric structure and direction has a bearing on the result, and thus the fabric was kept in the warp direction during assessment. Diffuse illumination was used to avoid the effect of the fabric structure. The images were captured in raw image format (NEF) to get uncompressed image details. The NEF image was converted into TIFF image format using Nikon ViewNX 2 software.

B. *Image Processing*

The relevant image was selected using a MATLAB program. Once the TIFF image was selected, the program read the image data into a variable matrix with dimensions W x H x 3, where W is the width of the image in pixels, H is the height of the image in pixels and 3 is the red, green and blue colour data for each pixel. Using the generated variable, the reference fabric sample and test fabric sample areas were selected. A 600 x 600 pixel square was used to crop the samples in the testing. The average of the 360,000 RGB values for each sample was calculated. Noise reduction filters were experimented with, but it was found that they did not show a significant difference to the result.

The RGB values thus calculated were then converted to the XYZ colour space using the following [10]:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = [M] * \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{9}$$

where

$$[M] = \begin{bmatrix} 0.4124564 & 0.3575761 & 0.1804375 \\ 0.2126729 & 0.7151522 & 0.0721750 \\ 0.0193339 & 0.1191920 & 0.9503041 \end{bmatrix} \tag{10}$$

The XYZ colour space is then converted to the Lab space as follows [10]:

$$\begin{aligned} L &= 116f_y - 16 \\ a &= 500(f_x - f_y) \\ b &= 200(f_y - f_z) \end{aligned} \tag{11}$$

where

$$\begin{aligned} f_x &= \begin{cases} \sqrt[3]{x_r} & x_r > \varepsilon \\ \dfrac{KX_r + 16}{116} & x_r \le \varepsilon \end{cases} \\ f_y &= \begin{cases} \sqrt[3]{y_r} & y_r > \varepsilon \\ \dfrac{Ky_r + 16}{116} & y_r \le \varepsilon \end{cases} \\ f_z &= \begin{cases} \sqrt[3]{z_r} & z_r > \varepsilon \\ \dfrac{Kz_r + 16}{116} & z_r \le \varepsilon \end{cases} \end{aligned} \tag{12}$$

Here

$$\begin{aligned} x_r &= \frac{X}{X_r} \\ y_r &= \frac{Y}{Y_r} \\ z_r &= \frac{Z}{Z_r} \end{aligned} \tag{13}$$

And

$$\varepsilon = 0.008856, \quad K = 903.3, \quad X_r = 0.950456, \quad Y_r = 1, \quad Z_r = 1.088754$$

calculating the colour difference using the DE2000 equations, weighting values of K_L=2, K_C =1 and K_H =1 are found to be suitable for textiles [11].

Once the colour differences were calculated colour difference ranges that give a correct grey scale rating had to be found. It was found that the ranges for colour difference values varied from colour to colour. Weights were therefore given to obtain one colour difference range that gives a correct grey scale rating. These delta E multiplication values were obtained to fit the manual grey scale rating with system grey scale ranges and also ranges that give grey scale rating by delta E values obtained to fit the manual grey scale ratings. Table II gives the weights used for different colours, while Table III gives the delta E ranges corresponding to different grey scale ratings.

TABLE III

WEIGHTS FOR DELTA E

Colour	Weight
Black	1.9
Yellow	1.1
Green	1.1
Red	1.5
Blue	1

TABLE IIII

DELTA E RANGES FOR GREY SCALE RATINGS

Delta E colour difference	Greyscale rating
0 to 0.3	5
0.3 to 2.3221	4/5
2.3221 to 2.79821	4
2.79821 to 4.6887	3/4
4.6887 to 6.2386	3
6.2386 to 8.5241	2/3
8.5241 to 11.0858	2
11.0858 to 13.2501	1/2
Greater than 13.2501	1

III. RESULTS & DISCUSSION

A large number of fabric samples of five different colours, namely black, red, green, yellow and blue were selected and tested. The test results were compared with the ratings obtained from manual assessment by expert assessors from the industry. The following graphs show the comparison between the manual rating and the computerised rating by the proposed system.

(e) Fig. 3 Manual & computerised grey scale ratings of fabrics

The foregoing shows that despite some small variations the two ratings are fairly well-matched. Some variations were seen due to errors in image capture, and in certain cases due to large scale variations within the fabric itself. Some disagreement was also seen between manual assessors. A limited number of hues only were used, and it is worthwhile carrying out further tests to see if the program would work with them as well.

It is further noted that the assessment was done using a D65 light source. If the assessment is to be done under different light sources some modification and calibration may be needed to the system.

IV. CONCLUSIONS

A promising system that could eliminate the subjectivity in manual assessment has been developed at a fraction of the cost of expensive systems such as spectrophotometers. The results of the system were found to be very close to those obtained from expert manual assessors. Further testing on a wider range of fabrics of different hues and structures would help to further develop the system and thus extend its scope to other types of colour fastness such as fastness to rubbing, perspiration, hot pressing, dry cleaning etc. It is also noted that only colour fading was assessed. The suitability of the system for staining should be investigated. Colour fastness to light is generally assessed using blue wool standards, and the program will probably need major modifications to test the same.

n general the system shows much promise, and with the above-mentioned developments could prove a viable alternative to more expensive systems on the market.

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