A New Method for Assessing Textile Fastness Based on Digital Imaging

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Abstract

Methods for assessing fastness of staining and colour change in textile industry have been widely for many years. However, they are tedious and based upon the judgements of experienced assessors. Although there are ISO methods based upon colour measuring instruments, they are still impractical due to the small size and poor uniformity of the specimens considered. In this paper, a new imaging system together with new fastness formulae have been developed and gave much more accurate results than the visual assessments based upon a group of professional assessors and the present ISO instrumental methods.

Introduction

Fastness is an important property for textile materials. Various fastness tests are carried out for each product prior to its manufacturing such as washing, perspiration, light, different chemicals. The final results are typically evaluated via visual assessments against a grey scale by professional colourists. Two types of assessments are considered here: one evaluating how much a colour has changed during a process such as washing, the other the degree of stain on an adjacent fabric. Two grey scales are recommended by ISO 105: A02[1] and Part A03[2] respectively. Each of the two grey scales consists of five pairs of grey scale samples arranged as shown in Figure 1. The number below each pair is the grade number. For each pair, the left-hand sample is identical to the right-hand sample denoted 5. Pair 5 thus has a zero colour difference since the same colour being used for both samples. The contrast between pairs increases from Grade 5 to Grade 1. The right hand sample in Part A02 (for colour change) is progressively lighter the lower the grade, while in the Part A03 scale (for staining) it is the opposite, with a white sample as the left-hand sample and the other samples progressively darker.

It is recommended that visual assessments should be carried out under an illuminance level of 600 lux, with a 45/0 viewing geometry using a daylight simulator representing north sky light. Grey masks should be used to mask all other colours except the pair in question and the test pair. Grade 5 of each scale is specified by CIE Y tristimulus value, i.e. Y of 12 ±1 and Y ≥85 for the A02 and A03 scales respectively. Increasing use is made of nine-step grey scales, in which four additional intermediate half grades (1-2, 2-3 etc) are added to the original five full grades. The ΔE^*_{ab} colour differences against the corresponding grades[3] are plotted in Figure 2.

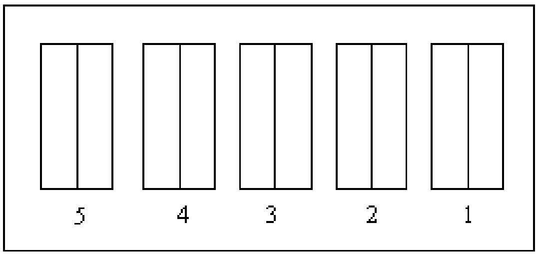


Figure 1. ISO Part A02 or A03 grey scales for assessing colour change or staining

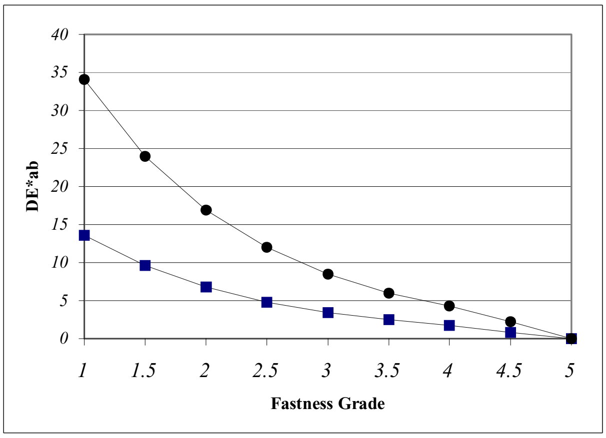


Figure 2. CIELAB colour differences of each pair for ISO Part A02 (square) and A03 (diamond) scales

The assessment process is highly subjective, and very expensive due to the involvement of experienced workers and the length of time needed. In a ring test carried out by the ISO/TC38/SC1 committee around 1980 it was found that there were large variations between results from different laboratories across different countries. At a later stage, this committee added two instrumental methods to the standard series: the ISO 105: Textiles – Tests for Colour Fastness, Part A04 (method for instrumental assessment of degree of staining of adjacent fabrics)[4] and Part A05 (method for instrumental assessment of the change in colour of a test specimen).[5] Both these methods are based upon modifications to CIELAB[3] colour space. However, they are alternatives to the corresponding visual methods (Parts A02 and A03) rather than replacements.

These instrumental methods have not been widely used due to spectrophotometer's limitations such as the difficulties in measuring very small-sized test samples. This is particularly the case for the standard testing sample in the form of 'multi-fibre strips' used for assessing staining specimens. Many of the specimens tested also have coloured patterns or are non-uniformly stained. Most importantly, considerable time is required to measure these samples in comparison with visual assessments.

This paper describes a new technique based upon the use of a digital camera system for assessing textile fastness. The system is comprehensively tested by the experimental results obtained from a number of professional colourists. In addition, two new fastness formulae have been developed to fit the visual results. They prove to be much more accurate than the current ISO formulae.

Imaging Techniques

An imaging system based upon a digital still camera, named DigiEye, has been developed and is used for capturing high quality images and measuring the colours within an image. The system has been reported elsewhere.[6,7] The system illustrated in Figure 3, includes a digital camera (1), a computer (2), a colour sensor (3) and an illumination box (4). The computer software includes four functions: camera characterisation, colour measurement, monitor characterisation, and texture profiling. In this study, the camera (1) was a *Canon Power Shot Pro90IS* camera. The computer (2) is mainly used to operate the system and includes software and a driver to capture images from the digital camera. The colour sensor (3) is used to calibrate the computer monitor for ensuring high fidelity colours displayed on the screen.

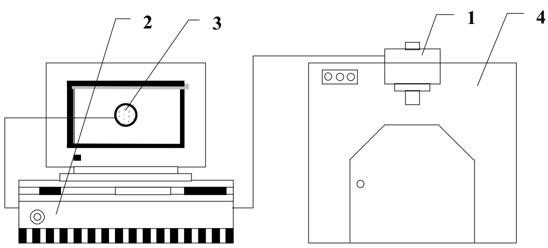


Figure 3. The DigiEye system

The illumination box (4) containing typically CIE illuminant D65 simulator, provides a stable and uniform illumination environment. The sample is illuminated by two sets of lamps at 45º to the sample. The illumination box used is critical for achieving accurate colour images because it provides a highly stable illumination environment. The camera is able to measure colours for each pixel of the image, and the software enables the average colour to be calculated for any desired area.

A 3 by 35 polynomial model[7] was developed to characterise the camera, i.e. to convert camera's RGB signals to CIE XYZ values. A GretagMacbeth ColorChecker DC target including 240 colours was used as calibration target. These were also used to test the system performance in terms of accuracy and precision. The results are 0.8 and 0.4 mean CIEDE2000[8] colour difference values for accuracy and precision respectively. This performance is considered to be highly satisfactory.

Experiment

Six data sets were accumulated for assessing staining and colour change fastness respectively. These are summarised in Table 1. The two 'UK' data sets were generated by the Instrumental Assessment of Colour Fastness Committee of the Society of Dyers and Colourists's Fastness Test Coordinating Committee during 1970-80s. All specimens in these two data sets were measured by various spectrophotometers at that time. The other four data sets were recently produced associated with this project and their specimenas were measured by a GretagMacbeth CE7000A d/8 spectrophotometer and the imaging system developed at the University of Derby. The specimens were prepared by TechniCare (TC), Procession Processes Textiles (PPT), and Marks and Spencer (M&S), and then assessed by their own assessors and those from other companies. This project has generated large interest from various national and international standard committees in textile. One data, TCI81, was generated by the British Standard Committee TCI8 including 38 assessors from 12 labs. In total, 601 and 445 pairs were judged by panels of professional colourists for staining and colour change, respectively.

Results and Discussion

Observer Errors

As mentioned earlier, each pair was assessed against a grey scale in terms of fastness grades by a panel of professional assessors. The observer variations were analysed in terms of inter-observer error and between-lab error. The former was calculated between results from all pairs of observers using root-mean-square (RMS) measure. For a perfect agreement between two assessors, the RMS should be zero. An RMS of 0.5 means an average variation of 0.5 grade in a scale from 1 to 5, and is the maximum error of assessment in commercial trade. The between-lab error was calculated between the mean results from the two particular labs compared. The RMS values between different pairs of labs were averaged to represent typical variations between labs in a data set. The results are also summarised in Table 1 marked 'Inter-obs. error' and 'Between-lab error'.

It can be seen in Table 1 that the inter-obs errors are larger than between-lab errors, and the variations of colour change data are larger than the variation of staining data. For staining data, all RMS values for observer variations are less than 0.5 RMS unit. This indicates that the visual assessments based upon a group of professional assessors are acceptable by industry, i.e. less than 0.5. However, in practice, the judgements are normally made by only a single individual assessor, rather than a group of assessors. Hence, the accuracy will be worse than those RMS values given in Table 1. For colour change data, the results are highly unsatisfactory, i.e. all inter-observer and between-lab errors are larger than 0.5 RMS units. This is mainly caused by the magnitude of colour differences, i.e. smaller colour differences for colour change pairs of samples than those of staining pairs of samples. Note that it is easy to perceive larger colour differences than smaller ones so that it often shows less observation errors for assessing larger colour differences than smaller ones. Overall, the widely used visual methods were found to be not that reliable.

The Performance of the ISO Formulae

All available specimens in the four data sets were measured by the imaging system and the spectrophotometer a few times to establish their repeatability performance. All the instrumental results were converted to the grades using the ISO A04 and A05 fastness formulae for assessing staining and colour change respectively. It was found that for the imaging system, their performances were 0.25 and 0.35 RMS units for staining and colour change respectively. For the spectrophotometer used, the repeatability performances were 0.21 and 0.25 RMS units for staining and colour change respectively. Although the latter performed slightly more repeatable than the former, the repeatability performance for the imaging system is still much better than those inter-observer and between-lab errors. In other words, the predictions from the imaging system should be sufficiently reliable for this task. In the following data analysis, only the results obtained from the imaging system are used.

The two ISO formulae were also tested using the experimental data sets accumulated. Again, the RMS measure was used to indicate its performance as shown in Table 1 marked 'ISO formula'. It can be seen that it is disappointing that their performances are worse than the inter-observer and between-lab errors for all cases except for M&S colour change data set. This means that the current ISO formulae provide unsatisfactory prediction for industrial applications. The combined for staining and colour change visual results are plotted against the predictions of ISO formulae in Figures 4a and 4b respectively. It can be seen that there are large scatters in both diagrams. Both formulae show a similar trend that they predict higher-grade specimens too high and lower-grade specimens too low. Also, there is a larger scatter in Figure 4b than that in Figure 4a.

The Development of the New Formulae

New formulae were also developed for assessing two types of textile fastness. The strategy applied was to combine three data sets in each type of fastness to form two combined sets. Various formulae were developed by optimising the coefficients in each formula in order to minimise the RMS measure to fit the two combined data sets. Finally, two formulae were obtained for assessing staining and colour change ass shown in equations 1 (SSR) and 2 (GSR) respectively.

$$\Delta E_{GS} = \Delta E - 0.423\sqrt{\Delta E_{00}{}^2 - \Delta L_{00}{}^2}$$
$$SSR = -0.061\Delta E_{GS} + 2.474\left(1 + e^{-0.191\Delta E_{GS}}\right) \quad (1)$$

where ΔE_{00} is the new colour difference formula proposed by CIE.[9]

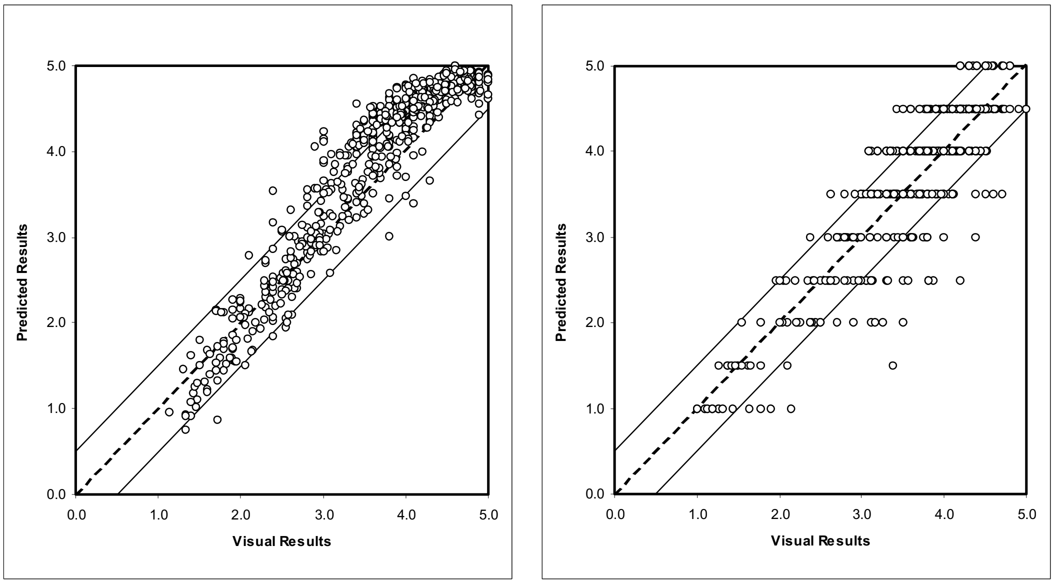
$$\Delta E_{GS} = \Delta E_{00} - 0.52\sqrt{\Delta E_{00}^2 - \Delta L_{00}{}^2}$$
$$\text{where} \quad \Delta E_{00} \quad \text{Computed}$$
$$\text{with } k_L = 1.0, \quad k_C = 0.5$$
$$GSR = 0.88 + 3.88e^{-0.2\Delta E_{GS}} \quad (2)$$

The performance of these formulae are also given in Table 1 marked 'Developed Formula'. It is very encouraging that there is a siginificant improvement of the newly developed formulae comparing with the current ISO formulae. The combined staining and colour change visual results are also plotted against the newly developed formulae in Figures 5a and 5b respectively. It can be seen that there are much smaller scatters in both diagrams comparing with those Figures 4a and 4b respectively. Although the scatter in Figure 5b is still somewhat large due to some inconstancy between the three data sets accumulated, however, it is still much smaller than that in Figure 4b.

Table 1. A summary of different fastness data sets and models' performance

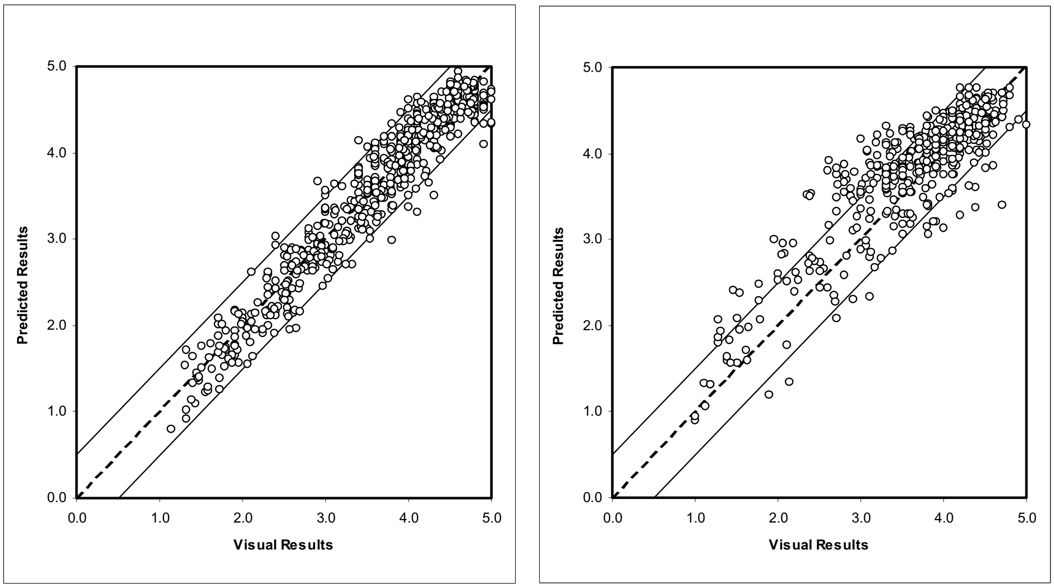
	No. of Pairs	No. of Observers	No. of Labs	No. of Observations	Inter-Obs. error	Between-Lab error	ISO Formula	Developed Formula
Staining Data								
PPT	114	8	2	912	0.39	0.36	0.55	0.29
TC	192	4	1	768	0.48	0.34	0.41	0.27
UK	295	35	9	10325	-	-	0.36	0.23
Colour change data								
UK	301	-	-	-	-	-	0.41	0.46
M&S	129	2-3	2-3	321	0.54	-	0.51	0.37
TCI81	15	38	12	570	0.68	0.53	0.82	0.37

Note: '-' means the results are not available.



(a) Staining (b) Colour change

Figure 4. The performance of ISO formulae for predicting combined data.



(a) Staining (b) Colour change

Figure 5. The performance of new formulae for predicting combined data.

Conclusions

An imaging system was developed for assessing two kind of fastness in textile trade: colour change and staining. Six data sets for assessing fastness were accumulated based upon large number of professional assessors. The data were used to evaluate the performance of observer variations and the current ISO formulae. It was found the observer variations in terms of inter-observer and between-lab errors are fairly large indicating that the visual assessment methods are not quite reliable. However, the performance of the current ISO formulae gave even poorer performance to fit the visual data. Finally, all available data were combined to fit two new formulae for staining and colour change fastness respectively. Their performances are highly satisfactory, i.e. much more accurate than a group of professional colourists and the ISO formulae. Currently, it is in the process to prepare three new British standards including a digital means for assessing textile fastness, a new fastness formula for assessing staining and a new fastness formula for assessing colour change.

This paper demonstrates that digital imaging devices can be properly characterised to be used as colour measuring instruments. The work described here is a revolution for a particular textile application.

Acknowledgement

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Biography

Guihua Cui received B.S. and M.S. degrees in optical engineering in 1984 and 1987 respectively at Beijing Institute of Technology, China and a Ph.D. in colour difference evaluation at the University of Derby in the UK in 2000. He is now working as a research associate at the CII. He served as an advisor for International Commission on Illumination (CIE) Technical Committee 1-47 on Hue and Lightness Dependent Correction to Industrial Colour Difference Evaluation.