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Measuring the Contribution of Texture to Colour Appearance

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Abstract

An investigation into colorimetrically calibrated colour imaging systems is reported which enable the analysis of the effect of texture on colour appearance. The analysis is based on measured colour and the CIE co-ordinate colour definitions of image pixels. Vectors are used to describe the variation in colour appearance of different textures, Each pixel colour is modelled as a component vector of the total light flux by which appearance is judged. The term Mean Colour Identity (MCI) is introduced, defined and proposed as a direct measure of the colour appearance of a surface. Variation of colour appearance due to texture is then defined and described by a Mean Vector Displacement (MVD) value from some appropriately defined reference Intrinsic Colour denoted as MCI_{ref}.

Introduction

This paper reports on part of a comprehensive EPSRC funded investigation[1] into colour and texture. The project aimed to establish as separate variables of colour appearance, a model of colorant formulations, and a model of the colour appearance of that formulation when applied to a given texture. The models are validated using a visual simulation of colour appearance on a computer screen that has been accurately calibrated [2,3,4], so that individual pixel colour can be controlled and reproduced to within an average ΔE 0.5 CMC(2:1) D_{65} CIE 10° Observer colour difference [5].

Photo-realistic images of a wide range of textures have been captured [6]. They focused on materials such as lace and sewing thread, multi-coloured melange yarns, and lustrous crepe fabric. The detailed colour differences between each point making up the surface texture have been recorded at a resolution of approximately 100 microns [7]. The definition of surface colour appearance produced, consists of many thousand CIE co-ordinate colour definitions arranged in a two-dimensional array of pixels, which combine to give a realistic simulation of a coloured textured surface.

The vector additive properties of Tristimulus values [8] are invoked, to model the relationship between variations in colour appearance due to texture, and the intrinsic colour represented by a colorant formulation. The paper seeks to establish quantifiable relationships between intrinsic colour and texture as distinct contributing variables of colour appearance.

The results of visual matching experiments are the basis for colorimetric modeling, and have been used to define the psychophysical attributes of the human sensation of colour [8,9,10,11]. They define on one hand colour identity, and on the other the modification of colour identity by factors external to the interaction of colorants with light.

Human observers are naturally skilled at judging when dissimilar textures are an acceptable match in colour appearance. In this investigation visual matching techniques have been combined with colorimetric analysis of matched images; in order to quantify colour appearance differences. Both the colorimetric accuracy of the data derived from images, and the accuracy of the matching process itself is assessed.

Surface texture effects are responsible for substantial visual colour shifts. Industrial colorant formulation only works well, if texture, measurement, and observation conditions are all held constant, and reflectance curve colour definitions generated for one texture or substrate, are often unsatisfactory for defining product colour in a different texture. The lace and sewing thread textures investigated [7] are good examples of this problem.

Visual Matching Based on Computer Generated Images

A considerable body of experimental evidence has been built up, reported in part here, on the utility and accuracy of visual matching experiments using computer generated images. Convincing images, with a high level of surface detail, can be produced and manipulated in colour on the computer screen, using the systems developed for the Imagemaster CAD system for colour communication, [12,5,7]. It is then possible to quantify and reproduce individual screen pixel colour to a level of accuracy comparable to the visual and colorimetric effects we wish to study.

Combining realistic images, accurate pixel colour, and the freedom to manipulate the colour of objects within an image has allowed the development of alternative methods for investigating colour appearance.

The visual matching process itself has been investigated, in order to establish the level of visual and numeric accuracy achievable using on-screen colour simulation in colour matching experiments. A second objective was to quantify the reproducibility of individual judgement, repeated assessment, and individual observer results compared with equivalent colour measurements. The variability of such observer trials requires output to be generated from multiple observations, (See Results tables 1 & 2), and it is important for the results of on-screen matching experiments to be subjected to statistical analysis for significance.

During experimental investigation, it is important to recognize the presence of quantized colour change on-screen [3], metameric matching effects, and colour-in-context effects. The precise conditions under which matches have been made (for example ambient light and illumination levels) were also found to be important variables.

In the following discussion, some results are reported for the effects of texture on colour appearance. Results are given for on-screen matched pairs, and matches obtained in cross-media comparisons of physical samples to screen images. Where possible, confirmation of the effects reported is made, using conventional measurement techniques.

The definition of Intrinsic Colour

Spectrophotometers, constructed for either radiant flux or surface reflectance measurement, are designed to measure intrinsic colour as an average value for the light flux radiated or reflected from some selected area. Such a measurement is taken as a generally acceptable intrinsic colour definition characteristic of a colorant formulation. The combination of an intrinsic colour definition with some as yet undefined measure of the contribution of texture, is suggested as a method of specifying the colour appearance of a chosen formulation when applied to a given substrate.

Intrinsic Colour is defined as: -

> **'The colour identity and spectral reflectance distribution that is produced by a set of colorants, when it is combined with some reference substrate, and it interacts with a given light source'.**

By this definition, intrinsic colour is linked directly to the fundamental physical processes of light absorption and transmission, and it is freed from the higher level texture-related variables of construction and presentation, by which the colour appearance of a substrate may be modified.

A Colorimetric definition of texture

In a computer simulation of colour and texture, a set of coloured pixels, each having a unique CIE co-ordinate colour definition, occupies some defined area of the computer screen. *The Texture Colour-Set* thus created consists in colorimetric terms of a set of CIE co-ordinate specified colours, and a frequency of occurrence for each colour. They are clustered in colour-identity space as a variable density cloud of CIE colour definitions. Figs 1 to 3 below gives an LCH analysis of the distribution of pixel colours present in a typical texture image.

Fig 1

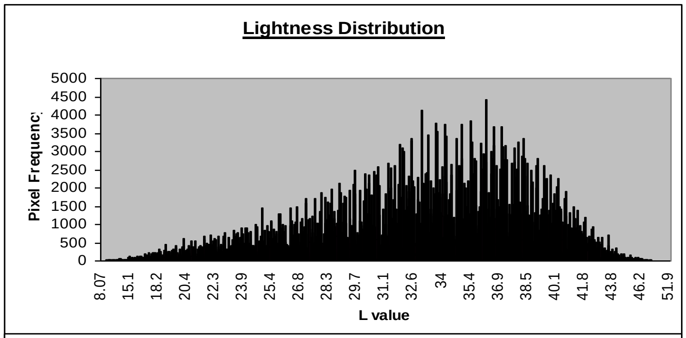


Fig. 2

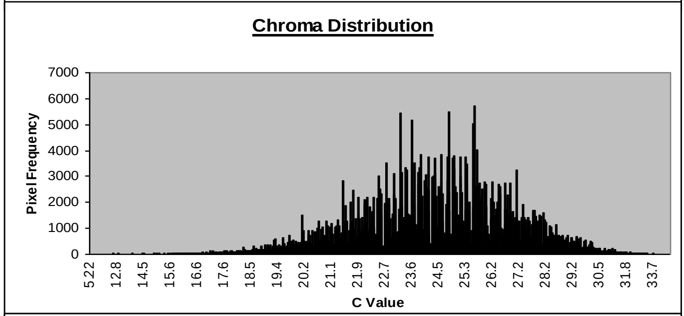
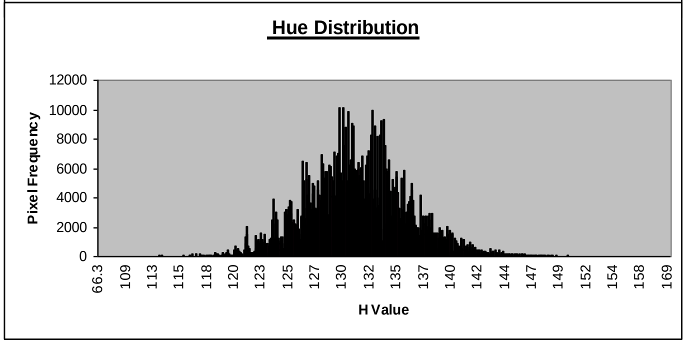


Fig.3



Figures 1 - 3, Pixel population distributions

For a medium depth medium chroma image of a textile yarn winding, judged by observers to have a single intrinsic colour.

It can be seen from Figures 1-3 that, although the image in question was of a plane surface, free of highlights and shadow, there are approximately 1500 different colours in the image, and a total of 58,000 pixels, whose colour and position make up the texture simulation.

The members of the colour-set are distributed in CIE XYZ colour-space as a cloud of points, centered around some as yet undefined intrinsic colour, which is assumed to have a single XYZ (and CIEL*a*b*) colour definition.

The Vector-Sum Colour (MCI or Mean Colour Identity) as a measure of a texture colour set

The use of vectors to describe colour sensations is based on the fundamentally linear additive equivalence of effect of light stimuli that is the central feature of CIE Colorimetry [8, 9]. Pixel colour specifications are modeled as possessing the linear additive properties of Tristimulus values, based on area weighted summation of contributing light fluxes.

The Vector sum of the light fluxes contributing to the visual appearance is given by: -

$$\text{M.C.I.}_{tex} = (\Sigma(X)/n, \Sigma(Y)/n, \Sigma(Z)/n)$$

The MCI is thus the mean tristimulus colour specification of all the contributing points on the surface under observation using the area weighted vector sum of the individual pixel colour specifications.

Its interpretation is clear, for objects judged to be of a single intrinsic colour. Its meaning is less clear for inherently multi-coloured objects.

MDD (Mean Directional Deviation) and MVD (Mean Vector Displacement) Values

The MCI defined above reduces a texture to a single base-colour. If the texture is changed, intrinsic colour constant, a measure of colour difference is required to describe the change (if any) in colour appearance. The standard CIEL*a*b* non-linear transformation of Tristimulus colour identity space, is used to project the additive vectors of colour difference into the vector-space describing colour identity.

DD_L *the direction of deviation in lightness is a vector* in colour-difference space. The vectors **DD_C** and **DD_H** complete the description. They are scalar measures in colour difference space, which have both direction and magnitude.

The convention that Metric Hue difference is an unsigned variable does not allow it to be treated as a vector. Directional Hue difference ΔH_D, is thus introduced as a scalar variable in CIEL*a*b* space, defined as:

$$\Delta H_D = \Delta H^* (\Delta h^0 / (| \Delta h^0 |))$$

where Δh^0 is the signed Hue angle change, $| \Delta h^0 |$ is its absolute value and ΔH is metric Hue difference.

Starting from the CIEL*a*b* MCI definitions (MCI_{Ref} and MCI_{Sample}), *vector displacements* , MDD_L, MDD_C ,*and* MDD_H *are defined for the lightness chroma and hue* dimensions of difference.

MDD_L is defined as follows: - $MDD_L = \Delta L (MCI_{Ref} - MCI_{Sample})$

Where MCI_{Ref} is the definition of intrinsic colour, and MCI_{Sample} defines a potentially different colour appearance, produced by combining the same intrinsic colorant formulation with a different texture.

MDD_L, via image pixel content MCI, defines the *mean directional deviation* of all the members of a colour-set from the intrinsic colour in the lightness dimension of difference, and is measured in CIEL*a*b* units, MDD_C , *and* MDD_H define the other two dimensions of mean directional deviation.

Mean Vector Displacement, MVD.

Single dimension MDD values are combined to give a three-dimensional '**Mean Vector Displacement Value'** (MVD) that describes the difference between MCI values, and hence the varying contribution of texture to colour appearance.

The three vector-component scalars are combined to give the Mean Vector Displacement: -

$$MVD = (MDD_L, MDD_C, MDD_H).$$

The colour-set, from whose colour definitions MVD values are calculated, is tested below as an analogue of a textured substrate, into which any intrinsic colour can be injected. The intrinsic colour (MCI_{Ref} colour) is an analogue of a colorant formulation that might be applied to the substrate.

Experimental Methodology

Deriving a value of visual colour appearance

Differences in colour appearance (colorants constant) may arise at the polymer level, fibre size or structure level, yarn structure level, or fabric construction level. In this paper we hold all the variables below the fabric structure level constant, by constructing a range of textures from identical yarns. The resulting materials have identical intrinsic colour, and substantially varying MCI colour appearance.

The fundamental Intrinsic Colour is equated to the measured colour of some reference fabric, and in the following analysis, MDD and MVD values are calculated with respect to the MCI of the yarn winding.

Visual assessment was based on photo-realistic on-screen simulations and physical samples in a light booth, using an accurately colour-calibrated computer screen to present screen simulations

'Texture-constant, varying intrinsic colour', and 'constant colour, varying texture' simulations were used, to obtain the observer 'panel mean' judgement of what constitutes matching colour appearance pairs, with results reported here, and by Oulton and Porat in [7]. Observer acceptance of equivalent colour identity is recorded as individual observer, and agreed 'Panel Mean' matches. This allows analysis of the effect being investigated, and of inter-observer agreement. A database, of colour definitions for each matched pair was recorded. When the match involves a textured image, the database is derived from screen-pixel definitions.

The simulation medium and the observation conditions were held constant throughout the experiments. Matches are made under constant spatial observation geometry, and constant colour-in-context conditions. The investigations thus focus on a single experimental variable, the effect of texture on the judgement of apparent colour.

The investigations described aim to validate the hypothesis that there is a measurable, constant, or at least analyzable relationship between the definition of the texture colour-set, and the colour identity of the object being observed.

A polyester yarn, common to all samples, was dyed to 20 different colours. The yarns were then fabricated into three textures: knits, windings and fibre-end tufts of controlled density. There are therefore, sixty samples in total. The 20 colours chosen were in five hues, (Red, Yellow, Green, Cyan and Violet). There are twelve samples in each hue group (four shades of Red etc, in each of three textures). The samples (e.g. Reds 1 - 4) in each hue group are differentiated by either low or high lightness and low or high chroma. Across the range of hues, there are thus four distinct colour groups, 'Low lightness and low chroma', 'low lightness and high chroma', 'high lightness and low chroma' and 'high lightness and high chroma' (see Appendix 1 Table I).

Results

Quantification of Visual Matching Accuracy and Reproducibility

In a separate series of experiments [13], multiple observations were carried out in a variety of matching tasks, ranging from the matching of plain-tile pairs on screen to cross-media matches of lace samples in a light booth with on-screen images of the lace. Full details will be reported separately, and the results are summarized here for reference. A predicable loss in numerical (CIE colour identity) equivalence between the objects matched is shown, as the difficulty of the matching task increases.

The accuracy of mean match results, is given in Tables 1a -1c below, for on-screen pair matching tasks, expressed as CIEL*a*b* D65 10^{o} Observer colour differences. As a general indication of observation agreement levels, the standard deviations of each set is given.

MATCHING OF PLAIN COLOUR TILE ON-SCREEN PAIRS.								
AVERAGE DEVIATIONS OF MATCHED COLOUR					STANDARD DEVIATION			
	DL	DC	DH	DE	Sigma DL	Sigma DC	Sigma DH	Sigma DE
RED	0.078	-0.028	0.638	0.644	0.152	0.411	0.020	0.176
ORANGE	-0.083	-0.026	0.702	0.708	0.381	0.460	0.029	0.359
GREEN	-0.159	0.105	0.687	0.731	0.132	0.300	0.062	0.167
BLUE	0.038	-0.568	0.836	1.012	0.120	0.561	0.030	0.243
LILAC	-0.129	-0.225	0.591	0.646	0.069	2.535	0.191	2.103

Table 1a. Matching single colour plain rectangular images in a simulated light box environment on-screen.

JERSEY FABRIC IMAGE ON-SCREEN PAIRS								
AVERAGE DEVIATIONS OF MATCHED COLOUR					STANDARD DEVIATION			
	DL	DC	DH	DE	Sigma DL	Sigma DC	Sigma DH	Sigma DE
RED	0.574	-0.137	0.760	0.962	0.395	0.464	0.005	0.328
ORANGE	0.728	-0.166	0.693	1.019	0.273	0.543	0.014	0.188
GREEN	0.396	-0.297	0.798	0.928	0.314	0.783	0.017	0.255
BLUE	-0.081	-0.593	0.902	1.083	0.176	0.697	0.005	0.254
LILAC	0.169	-0.693	0.926	1.169	0.059	1.114	0.032	0.428

Table 1b. Matching texture simulation images with identical texture detail, in a simulated light box environment on-screen.

LACE FABRIC IMAGE ON-SCREEN PAIRS								
AVERAGE DEVIATIONS OF MATCHED COLOUR					STANDARD DEVIATION			
	DL	DC	DH	DE	Sigma DL	Sigma DC	Sigma DH	Sigma DE
RED	0.333	-0.614	0.817	1.075	0.123	0.922	0.079	0.484
ORANGE	0.592	0.024	0.760	0.964	0.481	0.368	0.025	0.297
GREEN	0.285	-3.076	0.943	3.230	0.206	0.536	0.033	0.252
BLUE	-0.076	-0.518	0.578	0.780	0.263	1.998	0.202	2.019
LILAC	0.332	-0.416	0.732	0.905	0.079	0.526	0.014	0.301

Table 1c. Matching lace simulation images with identical texture detail, but significant colour variation, in a simulated light box environment on-screen.

From Table 1, (above) it can be seen that reasonable numerical accuracy of match is indicated by the mean values. The green lace image was reported as ‘difficult to match’ as it had both tonal and hue variations present.

The quantization step size for unit RGB change is very close to the values in Table 1a, and the matches were probably closer than the numerical values indicate.

For texture colour-sets, where many colour identities are averaged, quantization affects each pixel randomly, so the appearance of the texture will move more smoothly through colour-space. Table 1b indicates that the presence of texture in the simulation, even when it is identical in both images reduces the accuracy of matching by about Delta E 1 CIEL*a*b* unit.

With the more complex lace image, and the presence of distinct tonal variation, judgement is estimated to remain reasonably accurate.

Table 2a and 2b give the results for the more difficult task of screen to physical sample matching. Not only are the media (screen simulation, and physical sample in a light booth) different, they were separated by nearly 1 meter, and did not have precisely identical texture. The quality of match may also be affected by any or all of the known environmental variables of colour appearance change. Careful attention was however paid to equating illuminant type, light levels, and adjacent colour in order to minimize these effects.

JERSEY FABRIC SCREEN - TO - PHYSICAL SAMPLE PAIRS								
	AVERAGE DEVIATIONS OF MATCHED COLOUR				STANDARD DEVIATION			
	DL	DC	DH	DE	Sigma DL	Sigma DC	Sigma DH	Sigma DE
RED	1.80	1.380	0.878	2.432	1.69	1.441	0.014	2.340
ORANGE	1.43	-0.794	1.116	1.980	0.78	0.625	0.082	0.395
GREEN	0.40	0.734	0.976	1.285	0.58	0.876	0.037	0.549
BLUE	0.90	1.633	0.988	2.110	1.30	0.599	0.023	0.972

Table 2a- Mean results for multiple observations carrying out cross media matching, with the same texture type but not identical detail.

LACE, PHYSICAL SAMLE-TO-SCREEN IMAGE PAIRS								
	AVERAGE DEVIATIONS OF MATCHED COLOUR				STANDARD DEVIATION			
	DL	DC	DH	DE	Sigma DL	Sigma DC	Sigma DH	Sigma DE
PURPLE	-0.06	0.464	0.680	0.825	0.40	0.136	0.006	0.103
ORANGE	-0.29	-0.297	5.433	5.449	0.25	0.394	28.179	22.609
GREEN	-0.20	1.335	2.837	3.142	0.34	1.093	0.126	0.346
BLUE	-0.54	0.088	3.507	3.550	0.23	0.539	0.568	0.093

Table 2 b. Mean results for multiple observations carrying out cross media matching, with a lace sample, matched to an image of the same lace type.

From Table 2. It can be seen that there is a significant deterioration in match quality, when attempting cross-media matching of this type. The orange lace was regarded as extremely difficult to match, a fact confirmed by the very large SD value.

In an extensive cross-media matching investigation, Fairchild [14] reports comparisons of colour transparencies and prints with screen images. He found better levels of panel mean accuracy, than those reported here. They probably reflect the use of a prismatic device intended to bring the match components into visual proximity. High levels of inter and intra-observer deviations were however reported. The reported inter and intra-observer disagreement is ascribed by Fairchild, mainly to observer metamerism effects.

The overall standard of visual and numeric accuracy in the above sets, places the methodology comfortably inside the limits of accuracy needed to confirm the trends in colour appearance change reported below.

Match Validation by Spectrophotometry

All the results quoted for yarn windings and knitted structures are for differences that are also measurable using a spectrophotometer. In the case of the end-tuft structures, a special sample holder was constructed to allow them to be measured, using the small aperture mask on the SF600 spectrophotometer. The yarn windings exhibited quite strong variation of colour appearance with viewing angle. For visual matching, a viewing angle was chosen, that produced an **$\mathrm{MCI}_{\mathrm{Ref}}$** close to the measured value.

Table 3 below, compares MDD values between spectrophotometer measurements and visual matching panel mean values.

TEXTURE TYPE	**Spectrophotometer measurements**				**Values derived from Visual matches**		
	MDD_L	**MDD_C**	**MDD_h**		**MDD_L**	**MDD_C**	**MDD_h**
Tufts	-15.04	-2.45	1.18		-19.6	-1.2	1.9
Knits	-3.54	-1.70	-1.09		-11.1	-2.8	-2.4

Table 3 – MDD value colour differences (CIE L*a*b* units) derived from SF600 spectrophotometer measurements and from image analysis of visual match data, for the three textures.

When separate MDD_C and MDD_L values are calculated for each of the sub groups, individual trends are quantified. Figures 5 (a) - (d)., and Tables 4 and 5., show the results found from the visual matches, for each of the four lightness-and-chroma groups. The values are in CIE L*a*b* units, and are graphed for each texture type within each Hue.

TEXTURE TYPE	**Low lightness samples (all Hues)**			**High Lightness samples (all Hues)**		
	MDD_L	**MDD_C**	**MDD_h**	**MDD_L**	**MDD_C**	**MDD_h**
Tufts	-17.3	-5.0	1.1	-13.8	3.3	2.2
Knits	-10.4	-3.2	-2.3	-17.4	-3.8	-0.6

Table 4 : MDD values for Low Chroma samples (see Figs 5 a and b)

TEXTURE TYPE	**Low lightness samples (all Hues)**			**High Lightness samples (all Hues)**		
	MDD_L	**MDD_C**	**MDD_h**	**MDD_L**	**MDD_C**	**MDD_h**
Tufts	-15.1	-10.4	1.3	-24. 9	9.2	2.0
Knits	-5. 6	-3.9	-1.9	-13.9	-2.4	-3.8

Table 5 : MDD values for high Chroma samples (see Figs 5 c and d)

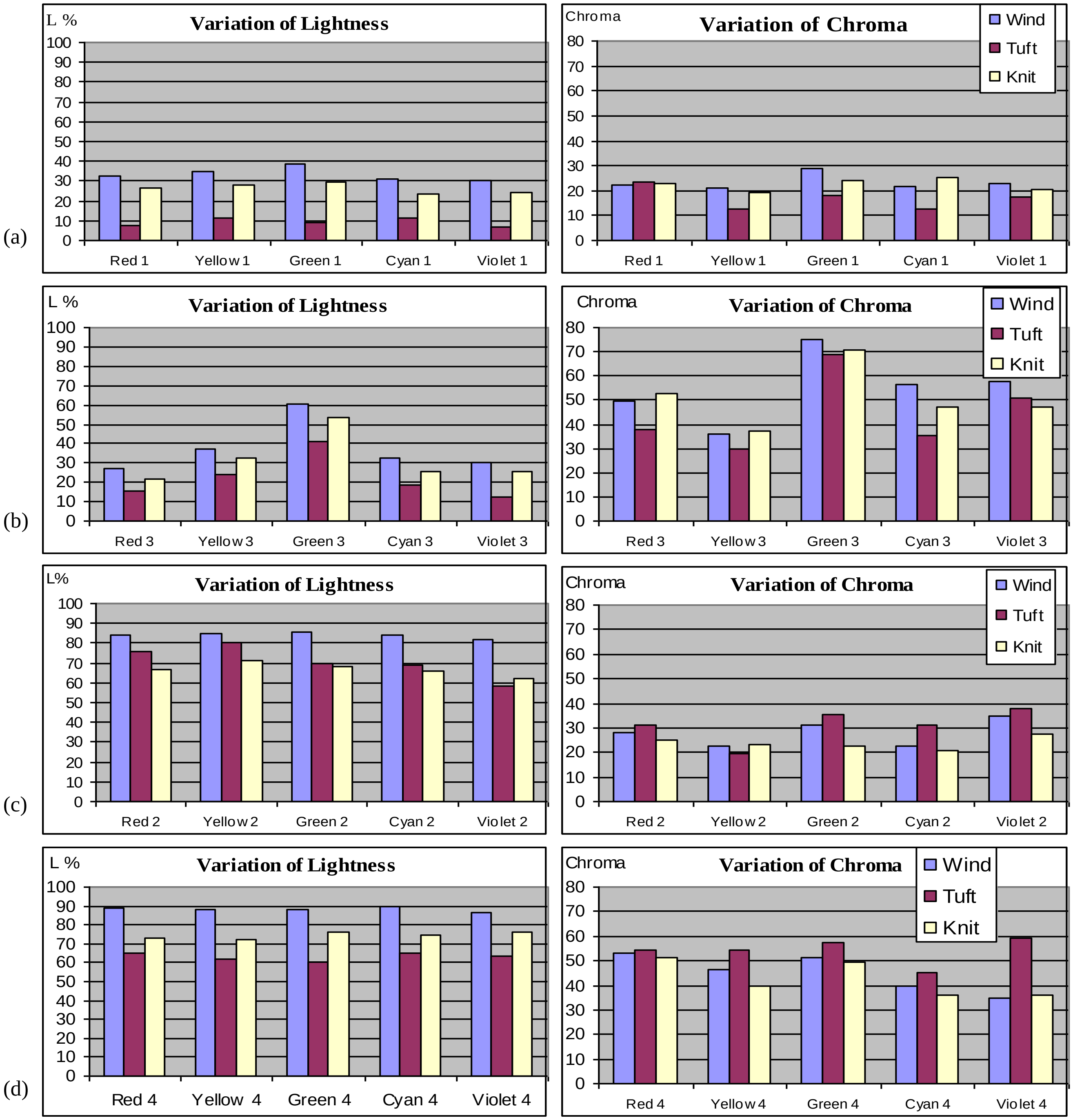


Figure 4. Variation of colour appearance with texture. (a) Low lightness, low chroma colours, (b) Low lightness high chroma colours, (c) High lightness low chroma colours, (d) High lightness high chroma colours.

Analysis of Texture-Specific effects

From Figure 4 it can be seen that MVD values quantify relatively consistent texture-related patterns to the variation of colour appearance. The winding texture is viewed and quantified as consistently lighter in all samples, compared to the other two textures. Knits are viewed as darker than the windings in all cases and tufts are usually darker or much darker than knits except in those samples shown in Figure 1c that represent the higher lightness and lower chroma group of intrinsic colours.

If the intrinsic chroma is low (a & c), the tufts are seen to increase in chroma relatively, in lighter shades. They move from lower relative chroma in dark shades to higher relative chroma in light shades. The knits are relatively lower in chroma at both lightness levels.

If the intrinsic chroma is high (b & d) the effect on chroma differentials is accentuated, for both tufts and knits, with a greater trend to increased chroma at high lightness in tufts, and a reduced negative chroma differential for the knitted structure.

The knitted texture shows markedly different characteristics from tufts, always being lower in chroma than the winding, and showing only a marginal increase in relative chroma at high lightness.

High chroma de-emphasises the lightness differential between the selected textures, but accentuates the chroma differential. Again the effects are somewhat different for the tufted structure compared to the knitted structure, even though they are made from the same yarn in each comparative case. All differences are given relative to the reference winding texture.

The overall MVD describes the effect (Intrinsic Colour Constant), of changing from the reference texture to an alternative texture:

Relative to the winding, $\mathrm{MVD}_{\mathrm{tuft}}$ = [-19.6, -1.2, 1.9] and $\mathrm{MVD}_{\mathrm{knit}}$ = [-11.1, -2.8, -2.4].

Conclusions

This paper introduces some measures of colour appearance based on imaging and visual matching methods. Image based colorimetric analysis was facilitated in these experiments, by the availability of accurately calibrated screen pixel colour.

Visual matching methods are inherently less accurate than colour measurements in quantifying colour differences, for both surface and on-screen colour. They can however be applied to a much wider range phenomena. The methodology also allows freedom to generate very large test sets of visually convincing on-screen simulations for assessment, covering many aspects of texture. The limitations of calibration accuracy, reproduction gamut, and quantization, described in the quoted papers, [2,3,4] must however be taken into account.

The accuracy in visual matching achieved, and expressed by multi-observation mean judgements, is shown to validate its use in the present context. The process is however critically dependent on the quality of the images presented, and on controlling the assessment environment precisely. The methodology must be employed with due care, and the results must be interpreted statistically to ensure their significance. In tables 1 and 2 there are four results, representing variation in one or more of the controlling factors. This causes observer disagreement, at a level, which significantly exceeds the quantity being measured. These entries indicate the need for careful control and result analysis, when using on-screen visual matching as an investigative tool.

MCI or Mean Colour Identity is defined and calculated as the vector sum colour of all the pixels in an image object, that contribute to its colour appearance. Each colour is weighted in the calculation, by pixel count. The convention of an MCI_{Ref} or zero point reference texture is used against which colour appearance differences can be compared, and used to define *Intrinsic colour.*

MVD and its component vector MDD values are defined as offsets by which the MCI differs from that of the reference texture.

The proposed measures could in principle be derived in many cases from conventional spectrophotometry, but there is however, a large class of colour appearance differences, that can not be measured practically by conventional large aperture integrating sphere methods.

The methodology for deriving colour measurements from images, is validated where possible by comparison with spectro-photometric methods.

Previously reported work [7] covered multiple instances of yarn windings of substantially varying colour. They were shown to have a characteristic and constant MCI relative to their measured colour identity. The reflectance curve was thus confirmed as a visually precise indicator of colour appearance (texture-type constant). The MCI is then a constant of the texture-type, across multiple yarn-winding instances, and across the set of intrinsic colours tested [7].

The choice of colours used in the experiments reported here is deliberately more extreme than the previous set, and was designed to test constancy of MVD values for varying textures, as the boundaries of reproducible colour space are approached. MVD appears to deviate measurably form the constant value previously reported. Preliminary indications, (Fig 4) are that deviations are a function of texture, chroma and lightness rather than of hue, and become significant at high chroma, and high lightness.

The size of deduced MVD as a function of texture, is substantial for winding to knit to tuft, even though the same yarn was used in each case to make the winding, knitted, and end-tuft structures.

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Appendix 1: Target and Test Colour Specifications

Test Colour	CIE L*	a*	b*
Red 1	26.78	19.59	0.32
Red 2	67.18	18.74	1.04
Red 3	25.88	36.66	1.15
Red 4	68.96	37.68	0.16
Yellow 1	25.95	5.97	18.45
Yellow 2	66.98	5.36	19.15
Yellow 3	33.28	10.69	31.63
Yellow 4	67.10	12.42	37.08
Green 1	27.69	-18.45	13.52
Green 2	65.18	-16.34	13.25
Green 3	48.90	-40.18	49.77
Green 4	66.25	-31.56	23.42
Cyan 1	25.58	-17.07	-10.15
Cyan 2	68.57	-15.93	-11.07
Cyan 3	36.53	-22.41	-13.33
Cyan 4	63.77	-24.21	-18.42
Violet 1	26.37	5.80	-17.85
Violet 2	66.85	6.46	-20.34
Violet 3	27.26	13.14	-37.22
Violet 4	68.20	8.88	-23.75

Table I CIEL*a*b* D65 10^o Observer measured values of the test colours.

TARGET MATCHING COLOURS FOR PLAIN TILE AND JERSEY FABRIC			
	L	C	h^o
RED	31.22	52.97	29
ORANGE	65.66	37.50	64
GREEN	40.64	61.17	141
BLUE	14.44	46.88	297
LILAC	47.78	52.97	344

LACE FABRIC TARGET COLOURS			
	L	C	h^o
PURPLE	25.58	12.21	324.62
ORANGE	54.43	34.6	56.02
GREEN	44.07	14.89	130.84

Table 2 CIEL*a*b* D65 10^o Observer measured values for visual match Target Colours.