1
The Incidence of Instrumental Metamerism, and its Effect on the fidelity of Colour Rendering by Cameras

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Abstract

The accuracy of image-capture is examined, in terms of reproduced colour co-ordinates. Variation in colorimetric accuracy, caused by detailed spectral variation in sensor response is discussed. The characteristics, both of human observers modelled by CIE Colorimetry, and of digital cameras are analysed.

The colour of images captured by a digital camera, is often visually incorrect. Colorimetric calibration, at output-channel level, and correct exposure under a suitable illuminant can reduce errors substantially, but colour-rendering of certain colours remain anomalous, even after colorimetric correction, due to instrumental metamerism. Specific colours, are incorrectly captured, exhibiting a marked hue or chroma shift relative to other colours in the imaged scene. They originate from metameric differences in response at the spectral level.

The potential size of metamerism effects are tabulated, their cause is discussed and demonstrated, and a proposed method for its quantification, based on images of Colour Charts is described.

Even minor differences in detailed spectral sensitivity are demonstrated to produce substantial effects on the numeric accuracy of colour-defining information in images. The effects are also related to the magnitude of human visual-system variation, by analysing the effects of variation in the CMFs of some of the component observers used to construct the 1964 Standard Observer. A colorimetric design for a camera is evolved, from which the output pixel-colour definitions are a close analogue of the measured CIE X, Y, Z Tristimulus values of the imaged surface colours.

Introduction

Conditional (or metameric) visual matches exist between certain pairs of surface colours with dissimilar spectral reflectance curves. The existence of such conditional matches is due to the summation of detailed variations in spectral stimuli, into a tri-stimulus model of the human visual response, reflecting its three-dimensional characteristics. The widely known phenomenon of ‘Illuminant Metamerism’, is complemented by and distinct from the less frequently studied phenomenon of ‘Observer Metamerism’.

Illuminant metamerism is evident when a single observer viewing a matching pair of surface-colour samples, sees a mismatch between the previously matching sample-pair, after the illuminant is changed.

Conditional mismatches produced by change of illuminant, are caused by variation in colour constancy between the members of the sample pair being matched. If both members change colour by the same amount, in the same direction, the match is maintained over the illuminant change.

A given reflectance curve has a specific property of colour constancy or colour inconstancy on change of illuminant. Colour inconstancy is discussed more fully by Luo, Hunt, Rigg, and Smith, in reference [1]. The effect depends on the light energy distribution at the spectral level in the illuminant, and on how the given energy distribution interacts with the detailed spectral response in the three colour-differentiating receptor channels.
Observer metamerism produces colour-definition changes on 'change of observer' (illuminant constant). It adds a new potential source of colour inconstancy, which modifies the effects generated by illuminant metamerism. On change of observer, variation in one or more of the receptor-channels can produce colour-specification change, adding more dimensions to the variables of conditional matching equivalence between a sample pair.

The three differentiating channels of response in the eye have relative sensitivity described by functions which map response with respect to wavelength. These Colour Matching Functions (or CMFs) vary slightly from observer to observer.

The Standard Observer is used as a constant reference, as one component of a metameristic observer-pair. The Standard Observer characteristic CMFs are paired with either measured individual human observer CMFs, or with a camera characteristic. An analysis is made of the pattern and incidence of observer-metameristic effects produced by different characteristics. Camera characteristics are also compared for colour-constancy effects in terms of size, variability and distribution with the established effects of human observer variability.

The chosen method for quantifying metameric difference on change of observer in this work, is the 1964 10° Observer colour-difference Delta E, CMC (2:1). It is calculated for a representative set of test colours, following the recommendations of Kuo and Luo in reference [2]. A previous paper by Oulton and Taylor [3] describes human visual variability, using the same quantification method.

In the following sections, both the spectral responses of the human visual-system, and the spectral characteristics of cameras are analysed for observer-metameristic effects. A design methodology for the spectral channel-response of cameras is described, which generates image-pixel colour definitions, that are a close analogue of CIE Tristimulus co-ordinates.

The Test-Colours used to detect and Quantify Observer-Metamerism

Two sets of test-colours have been used. One has 32 samples, defined by measured reflectance curves of samples from the NCS colour-atlas. The second set has 20 samples, defined by synthetic reflectance curves. The synthetic curves are more colour-constant over change of illuminant, than typical measured curves. They are otherwise directly analogous to surface-colour reflectance curves and give results very similar to those from the measured physical samples.

Four combinations of high and low lightness with high and low chroma, in eight or five hue-groups give 32 or 20 test-colours respectively. They were selected to cover a large volume of colour space. The 32-sample set was used to analyse the observer-metameristic effects of differences in human CMFs, the 20-sample set was used to analyse the effects of differences in spectral sensitivity of cameras.

The effects of change in observer are tested for given observer-pairs. Effects are quantified using predicted colour-specification change in the members of the relevant test-set.

Change of observer may then produce one of the following patterns of colour inconstancy -

- EITHER a pattern showing uniform change in colour specification.
- OR a pattern with a colour-constant characteristic
- OR, as is more likely, a pattern showing a detailed multi-dimensional variable effect.

The existence of a uniform change in colour-specification, would suggest that inherent illuminant-metameric properties of a given surface colour would be independent of change of observer. The
visual sensation perceived for a given surface colour might be different, but the observer would agree with the Standard Observer on the existence of conditional matches under a given illuminant.

*A colour-constant characteristic* is only shown by a strictly limited a class of non observer-metameric reflectance curves, which are visually equivalent to those of each of the physical test-colour samples. Members of this class of reflectance curve, have a specific curve shape that effectively 'cancels out' the given observer's differences at the spectral level.

*Non-uniform and possibly large differences* in change of colour-specification may be revealed on change of observer. This would indicate significant modification to the visually matching set of conditionally equivalent reflectance curves, generated by viewing under a specific illuminant.

**Deviations in the response of human observers**

Change of observer is shown to produce a range of variability in colour inconstancy, and of a typical size described by Oulton and Taylor [3], and quoted below.

Oulton and Taylor used the CMFs of 20 individual observers measured by Stiles and Burch [4]. The observers were component members the 1964 Supplementary Standard Observer-average, described in detail by Wyszecki and Styles [5].

CIE colour co-ordinates are calculated for the 32 measured reflectance curves of the test-set. The CMC (2:1) colour differences under D$_{65}$ Standard Illuminant, are calculated relative to Standard Observer co-ordinates for D$_{65}$. A total of 640 calculations of colour inconstancy on change of observer were made, across the set of test-colours.

**Results**

In Table 1, the pattern of colour-inconstancy revealed on change of observer, represents a general and variable lack of stability on change to the deviant observer. Tables 1a. and 1b. give the individual Hue-group, and mean $\Delta E$ (CMC 2:1, 1964 10° Supplementary Standard Observer) obtained for each of the test observers, across all the colour-groups.

The mean colour-specification change for all the colours and all the observers is $\Delta E = 0.97$ CMC (2:1). Six observers out of the 20 have a mean $\Delta E$ across the set of colours of more than 1. The individual observer maxima in Table 1 (overall maximum $\Delta E = 3.75$) represent substantial colour co-ordinate deviations.

<table>
<thead>
<tr>
<th>Colour Group</th>
<th>Actual Observers (Set 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WSS1</td>
</tr>
<tr>
<td>Blue</td>
<td>0.47</td>
</tr>
<tr>
<td>Blue-Red</td>
<td>0.44</td>
</tr>
<tr>
<td>Red</td>
<td>0.71</td>
</tr>
<tr>
<td>Red-Yellow</td>
<td>0.93</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.45</td>
</tr>
<tr>
<td>Yellow-Green</td>
<td>0.57</td>
</tr>
<tr>
<td>Green</td>
<td>0.33</td>
</tr>
<tr>
<td>Green-Blue</td>
<td>0.22</td>
</tr>
<tr>
<td>Overall</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Table 1a Observer Individual and Mean $\Delta E$ (CMC 2:1) For Each Colour Group, (Observers 1 to 10).
Instrument Metamerism in the Colorimetric Design of Cameras.

In this and the following sections, a computer-model is described which allows the colorimetric design of digital cameras to be analysed and optimised. The process involves minimising both the overall colorimetric, and instrumental-metameric error. Once overall three-channel colorimetric error has been minimised, the residual colour co-ordinate variation is derived from detailed variation of response at the spectral level. It is sample-specific, and due to n-channel response differences, and the pattern of colour inconstancy identifies instrument-metameric effects.

The process of response optimisation requires a downhill search, minimising the total Delta E for the colour-set. The three summed channel responses are automatically scaled and maintained in balance (constant area under the curve), while the cross-dependency matrix is adjusted. The model can also linearize sensor response, solving for an optimum fourth degree polynomial solution, if the measured characteristics of the camera under test has a non-linear response.

The minimum attainable Delta E equates to optimum three-channel calibration in terms of linearity, scaling, balance, and cross-dependency for the given spectral response characteristic.

A colorimetric characteristic is evolved, that is a very close analogue of CIE 1964 Supplementary Standard Observer. The output colour-specifications defining the image would in effect be equivalent to Standard Observer Tristimulus values, under appropriate imaging conditions.

The computer model generated takes as input:

1. The set of 20 surface-colour reflectance-curve definitions, selected as representative of real surface colours. The test-colours vary in chroma and lightness across the range expected in colour reproduction.

2. The set of 20 CIE Standard Observer colour co-ordinates for the 20 measured reflectance curves of the test-colours.

3. The Spectral Camera Characteristics under analysis (either directly measured, or modelled).

<table>
<thead>
<tr>
<th>Colour Group</th>
<th>MG11</th>
<th>PSW12</th>
<th>FJC13</th>
<th>JAR14</th>
<th>W15</th>
<th>JSP16</th>
<th>WDW17</th>
<th>JB18</th>
<th>GW19</th>
<th>DBJ20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>1.55</td>
<td>0.99</td>
<td>1.46</td>
<td>3.58</td>
<td>2.95</td>
<td>4.13</td>
<td>4.13</td>
<td>0.87</td>
<td>0.80</td>
<td>1.27</td>
</tr>
<tr>
<td>Blue-Red</td>
<td>0.21</td>
<td>0.26</td>
<td>0.43</td>
<td>0.85</td>
<td>0.54</td>
<td>1.29</td>
<td>0.33</td>
<td>0.16</td>
<td>0.13</td>
<td>0.64</td>
</tr>
<tr>
<td>Red</td>
<td>0.22</td>
<td>0.40</td>
<td>0.38</td>
<td>0.46</td>
<td>0.88</td>
<td>2.62</td>
<td>0.48</td>
<td>0.64</td>
<td>0.92</td>
<td>0.83</td>
</tr>
<tr>
<td>Red-Yellow</td>
<td>0.90</td>
<td>0.21</td>
<td>0.49</td>
<td>2.90</td>
<td>3.15</td>
<td>8.14</td>
<td>0.42</td>
<td>0.88</td>
<td>1.70</td>
<td>3.43</td>
</tr>
<tr>
<td>Yellow</td>
<td>1.01</td>
<td>0.46</td>
<td>0.87</td>
<td>3.00</td>
<td>2.86</td>
<td>2.20</td>
<td>0.86</td>
<td>0.57</td>
<td>1.08</td>
<td>3.04</td>
</tr>
<tr>
<td>Yellow-Green</td>
<td>0.55</td>
<td>0.35</td>
<td>0.68</td>
<td>1.67</td>
<td>1.52</td>
<td>0.74</td>
<td>0.64</td>
<td>0.26</td>
<td>0.38</td>
<td>1.55</td>
</tr>
<tr>
<td>Green</td>
<td>0.46</td>
<td>0.24</td>
<td>0.25</td>
<td>0.50</td>
<td>0.40</td>
<td>2.59</td>
<td>0.39</td>
<td>0.28</td>
<td>0.36</td>
<td>1.14</td>
</tr>
<tr>
<td>Green-Blue</td>
<td>0.80</td>
<td>0.45</td>
<td>0.54</td>
<td>1.52</td>
<td>1.27</td>
<td>2.90</td>
<td>0.39</td>
<td>0.51</td>
<td>0.73</td>
<td>2.30</td>
</tr>
<tr>
<td>Overall Mean</td>
<td>0.71</td>
<td>0.42</td>
<td>0.64</td>
<td>1.81</td>
<td>1.70</td>
<td>3.07</td>
<td>0.52</td>
<td>0.51</td>
<td>0.82</td>
<td>2.19</td>
</tr>
</tbody>
</table>

Table 1b Observer Individual and Mean ΔE (CMC 2:1) For Each Colour Group, (Observers 11 to 20).
The outputs of the model include:

1. 1964 10° Standard Observer CIE L*ab* co-ordinates for both the Standard Observer CMFs and the camera characteristic CMFs under analysis, for each member of the colour-set.

2. 1964 10° Standard Observer CMC (2:1) colour differences, between the Standard Observer and current camera response, calculated from equivalent balanced and scaled CMF definitions at the spectral level.

The 'Best Characteristic' primaries are chosen to have response maxima very close to those of the CIE CMFs, and to have a similar bandwidth.

The curves labeled 'Poor Characteristic', are deliberately perturbed, as shown in Table 2.

<table>
<thead>
<tr>
<th>Channel</th>
<th>B</th>
<th>G</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max at Nm</td>
<td>452</td>
<td>543</td>
<td>597</td>
</tr>
<tr>
<td>Bandwidth Nm</td>
<td>42</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Best Characteric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poor Characteric</td>
<td>455</td>
<td>550</td>
<td>610</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

Table 2. Overall input channel characteristics of the two camera configurations tested.

Physical RGB filter media are modelled using strict Gaussian response-distributions. This avoids detailed spectral effects related to specific filter media. The quoted bandwidth is equivalent to +/- one Standard Deviation either side of the mean, and thus comprises just over 68 % of the total response.

Measured filter/photo-receptor response combinations have also been used as input, to generate camera-response characteristics.

The basic camera RGB primaries are linearized and balanced with respect to the Y value of a measured target grey-scale if necessary. They are then combined by an adjustable RGB-to-XYZ matrix. Specific cross-dependency matrices are derived by optimization to give simulated X, Y and Z channel responses.

They are as follows:

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = \begin{bmatrix}
1.00 & 0.09 & 0.225 \\
0.55 & 1.0 & 0.10 \\
0.00 & 0.001 & 1.00
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}\]

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = \begin{bmatrix}
1.00 & 0.002 & 0.245 \\
0.43 & 1.0 & 0.19 \\
0.00 & 0.002 & 1.00
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

Figures 1 to 3 below, show the variation in detailed spectral response after overall colorimetric calibration, based on optimum matrix definition, balancing, linearization and scaling.
Figure 1.
Spectral variation in the synthesized 'X-Channel' response with wavelength, balanced to give constant area under the curve.

Figure 2.
Spectral variation in the synthesized 'Y-Channel' response with wavelength, balanced to give constant area under the curve.

Figure 3.
Variations in the synthesized 'Z-Channel' response with wavelength, balanced to give constant area under the curve.
Testing the Generated Camera Characteristics

If there is minimal calculated CMC (2:1) colour-difference across the test-set, on the change from Standard Observer to Camera, the camera design under test is assumed to be a close analogue of the human Standard Observer model. Exhaustive evaluation is however not feasible, for all possible n-dimensional variations of reflectance, or even for just the sub-set of smooth reflectance curves. The test-set is selected as being representative of typical variations in hue chroma and lightness.

The measured colour-difference (CMC (2:1) Delta E) values for the change from Standard Observer characteristics to instrumental sensor characteristics is illustrated in Figure 4. In each hue-group in figure 4,

![Delta E Difference with Choice of Primaries After Optimization](image)

Figure 4. Detailed variation of differences from the Standard Observer.

Combinations of lightness and chroma are ordered as follows in each hue-group, left to right -
1 = Low L plus Low C, 2 = High L plus Low C, 3 = Low L plus High C, 4 = High L plus High C.

When the 'optimum' RGB sensor primaries are used, the deviation of the calibrated camera response from the Standard Observer response is small across the full colour-set (see also Table 3). The resulting 'Best characteristic' response curves are also shown (Figures 1 to 3) to be very close to those of the Standard Observer. Deviations are relatively small in the blue part of the spectrum for both of the tested camera characteristics. This is due to the relatively small variation in the synthesized Z-channel response (figure 3), generated by moving the response maximum by 3 Nm, and reducing the bandwidth by 2 Nm.

The change in wavelength maximum of the Blue channel by 3 Nm on its own, does however add approximately 0.5 units to the average CMC (2:1) Delta E colour difference, across the test-set, as it affects all three of the (XYZ) output channels.

Slightly larger deviations were introduced in response maxima and bandwidth in the R and G input channel responses (Table 2.). Their effect on the X and Y channel responses is larger, (figures 1 and 2), producing a consequently greater metameric effect (figure 4) principally across the four lightness and chroma combinations in the red hue-group, but also to a smaller extent, in the yellows, greens and cyans.
Table 3, shows the residual metameric deviation from the Standard Observer response, for the 'Best Spectral Characteristic' model, compared with the 'Poor Spectral Characteristic' model. The magnitude of the largest deviation generated, is comparable to that found in the most deviant human observer (Table 1b).

<table>
<thead>
<tr>
<th></th>
<th>Best Spectral Characteristic</th>
<th>Poor Spectral Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Deviation</td>
<td>0.29</td>
<td>1.96</td>
</tr>
<tr>
<td>(CMC 2:1) units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Deviation</td>
<td>0.87</td>
<td>4.77</td>
</tr>
<tr>
<td>(CMC 2:1) units</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. The mean and Maximum Deviation from the Standard Observer Colour co-ordinates.

The colorimetric design methodology reported here was first developed and applied, using strict Gaussian response models of real filters. It has also been applied to characteristics based on real combinations of measured photo-sensor and physical filter-media responses. The adopted principles of design optimization work equally well when applied to real primaries, but the optimum configuration is potentially a less accurate analogue of the Standard Observer.

Conclusions

'Change of Observer' introduces an additional element of colour-sensation inconstancy in surface colour appearance. The colour-inconstancy produced has properties that are analogous to that caused by change of illuminant, and adds to (or subtracts from) the effect of the illuminant.

A computer spreadsheet model was used, to set up and test a wide range of spectral response characteristics. In the case of cameras, the input was data representing numerically modelled RGB sensors. Measurements of physical filter/sensor combinations have also been tested for colorimetric accuracy in the model. In the case of human observers the input data was measured human CMFs.

The model allows a calibrated and optimized three-channel colorimetric solution to be developed for each given sensor configuration. Residual instrument-metameric effects are then available for analysis.

The size of instrumental-metameric error is often significant, and can represent a major part of the total colorimetric error in an un-calibrated imaging system. Such errors are usually concentrated in specific hue-related sub-sections of colour-space, and are not confined to high chroma colours (Figure 4.).

Any metameric error present in the colorimetric design of a camera, represents an irreducible minimum of image-specification error, that can not be eliminated by three-channel calibration. The errors are a function of sensor-response design at the spectral level. The Cyan, Yellow and Magenta hue-groups tend to demonstrate strong instrumental-metameric effects. These hue-groups correlate with spectral regions, in which cross-over points are present in relative sensitivity, and there is rapidly changing sensitivity of channel response.

Modelling and testing metameric error.

Testing different camera characteristics, involved deliberately introducing small variations in modelled colorimetric properties that distinguish the characteristics under test from those of the CIE 1964 Standard Observer. The characteristics being analysed, and the Standard Observer are treated as an observer-pair, and the effect of change of observer is analysed.
Calibrated equivalence to the Standard Observer response at the three-channel level is first established by balancing, linearization and scaling of the overall cumulative channel responses.

The effects of two synthesized spectral response characteristics are reported. One of these, (the 'best spectral characteristic') closely follows the spectral characteristics of the Standard Observer (Figures 1 to 3). It is shown to be capable of both low general colorimetric error, and low instrumental-metameric error (figure 4.). The other ('poor characteristic') is deliberately perturbed, by small variations in response-maximum, and bandwidth. The introduced changes in spectral sensitivity are in general smaller than the equivalent differences found in the measured spectral responses of some commercial cameras [7].

The Red and Green responses of the CIE Standard Observer overlap substantially. It is thus possible to minimize the effects of incorrect bandwidth by deriving an optimum cross-dependency matrix for the changed primaries. The optimum matrices (1) produce a cross-product of R and G in proportion, in order to construct synthesized X and Y responses after overall three-channel calibration. The process generates an equivalent, but rather uneven spectral response in the case of the 'poor' primaries (figures 1 and 2.). Optimization is less effective for the Y primary, as the synthesis involves significant quantities of all three primaries. The effect can be seen in Figure 2, which shows the synthesized Y responses, balanced and scaled at the three-channel level against the Standard Observer response.

It is less easy to compensate for the effects of an incorrect blue-channel response, due to the substantial difference in its wavelength maximum from that of the R and G sensor input. An incorrect response maximum in the blue channel can however be compensated if a fourth channel is introduced, with a much smaller wavelength differential. In such a four channel camera, it is possible to reduce metameric error to very low levels, by appropriate choice of filter design. Introducing a fourth channel gives more degrees of freedom for optimizing the cross-dependency matrix between the four channel-characteristics, and X,Y,Z channel output.

The matrices quoted (1), represent the changes required, to re-optimize cross-dependency after changing the primaries as indicated in Table 2. The revised 'best characteristics' matrix was used to generate the device-output X,Y,Z analogues of the CIE 1964 10° Supplementary Standard Observer, giving low instrument-metameric deviation (Table 3.).

The quoted colour differences are relative to the measured spectral reflectance curves of the physical samples imaged by the camera.

**Colorimetric design methodology.**

The 'RGB' definition of each pixel in an image from a digital camera, is only an analogue of the human visual response, in-so-far as it uses three primaries spaced across the spectrum. By contrast, the physical colour being imaged is defined by its spectral reflectance characteristics, and its visual effect is accurately modelled by CIE Standard Observer Tristimulus values.

A camera that has outputs that are a close analogue of CIE Standard Observer Tristimulus Values is assumed for the purposes of this research, to have theoretically perfect colour rendering. This is only true however, if the scene being imaged is illuminated by light which closely approximates Standard Illuminant D65, because of the potential for additional Illuminant-Metameric effects.
A technique is presented, for colorimetric design of channel response, at both the three-channel colorimetric level, and at the spectral level in terms of metameric effect. It is suggested that the methodology described, could form a suitable objective basis for assessing the effects of both theoretical and practical filter/sensor combinations, and optimizing their colorimetric design.

The visual effects of calibration and testing are reported separately by Dr Yu [6]. He demonstrates that colours exceeding Delta E 3 CMC (2:1), are judged to be a 'poor match' when included in a composite image. Any camera with a response similar to the 'poor characteristic' would produce noticeably inferior colour rendering, particularly of the reds in any image, even if the image was captured at optimal exposure.

Achievement of low instrumental-metameric error, enabling low overall calibration error at the three-channel level, is the scientific objective of the colorimetric-design method. It remains to be demonstrated however, that a camera-characteristic design with low metameric error could be implemented in a real camera. It is also not necessarily true, that such a design would produce a pleasing visual appearance in terms of reproduced colour.

Acknowledgements

The research described arises from DTI Link Project AFM/65 "Colour Calibration for Food Appearance Measurement". The work by Dr Pointer and Prof. Attridge at the University of Westminster during the project, provided some of the background data, and also the camera-system design principles used in the modelling process.

Work on Project AFM/65 Work-Package 1. also highlighted the significance, and potential contribution of metameric effects to image colour inaccuracy.

The authors are also indebted to Helen Taylor for contributing the analysis of human observer variation [8], and subsequently revising the data to give results as CMC (2:1) colour differences.

Bibliography