A Color Reproduction Index

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Abstract

The steps involved in determining a Color Reproduction Index are described. The Index is based on differences in Hue, Lightness, and Chroma (or Colorfulness), as evaluated by a model of color vision, for a reference and a test situation in which the viewing conditions may be different. The color quality of reflection prints made at different printer settings was evaluated by means of the Index and by observer judgements, and a reasonably good correlation was obtained.

Introduction

The development of the quantitative measures, acutance and granularity, that correlate, respectively, with sharpness and graininess, has greatly facilitated the development of improved systems of colour reproduction. This means that assessment of the merit of color changes has to be made qualitatively, and this is vulnerable to prejudice, fluctuating opinions, and individual idiosyncrasies in color vision and color preference. A color reproduction index is needed to provide such quantitative measures. The use of conventional colorimetry and color difference formulae are only appropriate if the original and the reproduction are seen under the same viewing conditions; when these conditions are different, they must be allowed for, and this can be done by using a suitable model of color vision. Even when the viewing conditions are the same, it is still useful to use a color vision model, because this can provide accurate measures of hue, and this attribute, being the most critical, usually has to be weighted more heavily than other color attributes. The color reproduction index described in this paper is based on the work of Pointerl, and makes use of the Hunt 94 model of color vision[2,3].

Steps In Using A Colour Reproduction Index

The following steps can be used to determine a color reproduction index.

Step 1. Define Reference and Test Situations.

A color reproduction may be produced from an original or from another reproduction; the originating material is regarded as the reference, and its viewing conditions as the reference situation. The reproduction produced is regarded as the test, and its viewing conditions as the test situation. For example, the reference situation might be a selection of colors on a chart seen in daylight, and the test situation might be a reflection print of the colours viewed in tungsten light.

Step 2. Measure or Compute Photometric and Colorimetric Data for the Reference and Test Situations.

The following data are needed:

Reference Situation:	Adapting luminance, L_A
	Tristimulus values, X, Y, Z
Test Situation:	Adapting luminance, L_A
	Tristimulus values, X, Y, Z

Step 3. Use a Model of Colour Vision to Obtain Colour Appearance Measures for the Reference and Test Situations.

Reference Situation:
Hue, Lightness, Chroma (or Colorfulness)
Test Situation:
Hue, Lightness, Chroma (or Colorfulness)

Compute the differences in Hue, ΔH, in Lightness, ΔJ, and in Chroma, ΔO_{94} (or Colorfulness, ΔM_{94}). If there is no difference between the reference and test adapting luminances, either chroma or colorfulness can be used. If there is a difference, colorfulness is used if the effect of the difference is to be included, and chroma if it is to be excluded, because, for instance, of the influence of cognitive factors.

Step 4. Compute the Hue-Weights for Each Colour in the Original in the Reference Situation.

In order to make the color reproduction index diagnostic, it is useful to determine the performance separately in different areas of color space; in particular it is useful to know separately what happens to reddish, yellowish, greenish, and bluish colors. This is done by weighting the contribution of each color to these four hue segments according to its reference hue. For example: for a color of Hue Composition 75G 25Y the weights are:

R=0 Y=25 G=75 B=0

Step 5. Compute Absolute and Relative Color Reproduction Differences In Each Hue Segment.

If the reproduction differences were averaged, equal and opposite differences would cancel out, suggesting that there was no difference. It is therefore necessary to take an average ignoring the signs of the differences, and this is called the ABSOLUTE Color Reproduction

Error. However, it is also important to know the direction of the error, and for this purpose the average is also calculated using the signs to obtain the RELATIVE Color Reproduction Error. Hence the ABSOLUTE Color Reproduction Error shows the magnitude of the average error; and the RELATIVE Color Reproduction Error shows its average direction, a zero value indicating that the differences were equally balanced in direction.

The ABSOLUTE and RELATIVE Color Reproduction Errors are computed as follows.

(a) Weight the differences ΔH, ΔJ, ΔO_{94} (or M_{94}) according to the hueweight for each colour.

(b) Compute the average of the weighted differences, ignoring the signs, to obtain the ABSOLUTE Colour Reproduction Error, for each hue segment.

(c) Compute a similar average using the signs to obtain the RELATIVE Colour Reproduction Error, for each hue segment.

Example	Colour Reproduction Errors			
Absolute	Red	Yellow	Green	Blue
ΔH	6.3	9.4	14.0	13.4
ΔJ	7.6	7.8	7.2	5.9
ΔO_{94}	10.5	8.1	11.7	10.9
Relative	Red	Yellow	Green	Blue
ΔH	2.2	-7.6	1.9	-5.3
ΔJ	-7.2	-7.7	-7.2	-5.2
ΔO_{94}	6.9	0.0	-11.6	-5.6

For the RELATIVE Errors, positive values indicate that the Hue, H, changes in the directions red to yellow to green to blue to red, and negative values in the opposite directions; for Lightness, J, and for Chroma, O_{94} (or Colorfulness, M_{94}), positive values indicate an increase in lightness and in chroma (or colorfulness), respectively, and negative values a decrease.

Step 6. Compute the Color Reproduction Index and the Average Error Direction for Each Hue Segment.

It is convenient to arrive at Color Reproduction Indices that are 100 for zero absolute errors, and that decrease progressively below this figure as the errors become larger. This is achieved as follows:

(a) Subtract each ABSOLUTE Colour Reproduction Error from 100 to obtain the Colour Reproduction Index for Hue, Lightness, and Chroma (or Colorfulness) for each hue segment.

(b) Use the RELATIVE Colour Reproduction Error to indicate the Average Error Direction for each hue segment.

Example	Colour Reproduction Indices				
	Red	Yellow	Green	Blue	Mean
Hue	93.7	90.6	86.0	86.6	89.2
	R→Y	Y→R	G→B	B→G	
Lightness	92.4	92.2	92.8	94.1	92.9
	Dark	Dark	Dark	Dark	
Chroma	89.5	91.9	88.3	89.1	89.7
	Strong	Equal	Weak	Weak	

The twelve Color Reproduction Indices obtained in this way are useful for guiding development work; but at some stage it is often necessary to have to decide whether to implement a package of changes or not. For this purpose some kind of overall index is required. Obtaining this may invite the accusation of having an attack of mononumerosis, but in practical situations a single decision has to be made: whether or not to adopt a package of changes. In the above example an overall Index is therefore given by averaging the twelve individual results; more sophisticated averaging can be carried out, which can allow for the different numbers of samples in each segment, and can give more weight to some errors, such as those in hue, than to others.

A Practical Test of a Color Reproduction Index

The Color Reproduction Index has been tested in several studies[4,5,6], one of which will now be briefly described[5].

A scene was photographed on to a color negative film, and immediately afterwards, on the next frame of the film, a MacBeth checker chart was photographed by placing it in front of the camera which had not been moved. This was repeated three times, to produce negatives of four different scenes designated as, green foliage (G), blue sky (B), Caucasian skin (C), and Sandy Beach (S). The scene G negatives are referred to as G1 for the scene and G2 for the chart, and similarly for the other scenes. The processed negatives were then printed and the prints evaluated as follows.

Step 1. The printer setting was found that resulted in negative G2 giving prints with neutrals on the chart reproducing as neutral.

Step 2. Prints were then made from negatives G1 and G2 at controlled printer settings differing from that found in Step 1 by various amounts in the red, green, blue, cyan, magenta, and yellow directions (densities on the prints deviated from neutral by up to about ± 0.3 in red, green, and blue).

Step 3. Steps 1 and 2 were repeated for negatives B1, B2, C1, C2, S1, and S2.

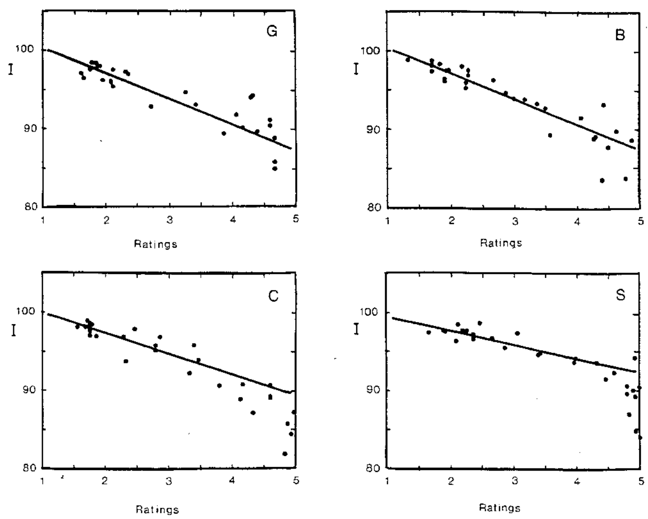

Figure. Overall Color Reproduction Index, I, *plotted against observers' judgement ratings for four scenes: green foliage (G), blue sky (B), Caucasian skin (C), and sandy beach (S).*

Step 4. Quality judgements of the scene prints (made from G1, B1, C1, and S1) were made and compared to Color Reproduction Indices derived from colorimetry of the chart prints (made from G2, B2, C2, and S2), using the Hunt model to give measures of Hue, H, Lightness, J, and Colorfulness, M, (not Chroma). The overall Index, I, was calculated as $(2I_H + I_J + I_M)/4$where I_H is the index for Hue, I_J that for Lightness, and I_M that for Colorfulness. The judgements were made by 10 observers in artificial daylight having a correlated color temperature of 6500 K at an illuminance of 1650 lux. A five point category scale was used to provide ratings for the prints: 1 Excellent; 2 Good; 3 Acceptable; 4 Poor; and 5 Unacceptable.

Step 5. The overall Color Reproduction Index was plotted against the average observers' scaling category for each printer setting for each scene. The results are shown in the figure.

It is clear from the figure that there is a correlation between the overall Color Reproduction Index, I, and the observers' average ratings. The bunching of the points at the right hand end of the plots for scenes C and S suggests that even better correlations would have been obtained if categories worse than 5 had been available to the observers. These results indicate that the color reproduction quality of systems can be evaluated meaningfully using a Color Reproduction Index based on a model of color vision, and using a chart of selected colors. Further work is needed to test the validity of the method in other applications, and to determine whether a different selection of colors than those provided in the MacBeth checker chart would improve the performance of the Index. The reason for using a chart, rather than carrying out colorimetry on elements of the actual scene, is that the latter is fraught with many practical difficulties arising from factors such as uneven scene illumination, texture, and flare and vignetting in the camera and in the printer.

References

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