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Can the Problems of CIECAM02 Be Overcome without Losing Predicting Accuracy?

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Abstract

While CIECAM02 enjoys its popularity as being widely used in academic research and industrial applications, some problems are also identified. Unexpected computational failure is one of the important problems concerned by the cross-media colour reproduction industry. In the past few years, many suggestions are proposed for solving the convened problems under the same structure of the original CIECAM02. All the extension proposals have one thing in common that is at the expense of losing predicting accuracy compared with the original. In this paper, the chromatic and luminance adaptations are combined in one space rather than in two separate spaces in the original CIECAM02. The new proposed version not only overcomes all the problems concerned related to the CIECAM02, but also performs equally well or better than the original in predicting the visual corresponding colour datasets and the colour appearance datasets. Furthermore, it is simpler than the original.

Introduction

Ever since the recommendation of the CIECAM02 colour-appearance model by CIE TC 8-01 Colour appearance modeling for colour management systems, it has been used to predict colour appearance under a wide range of viewing conditions [1-3], to specify colour appearance in terms of perceptual attributes [4-6], to quantify colour differences [7], to propose a uniform colour space and to provide a profile connection space for colour management [9-11]. However, it was found that there are problems with CIECAM02. One of the main problems is that the domain of the CIECAM02 is smaller than the ICC connection space, causing unexpected computational failure during the transformations using the CIECAM02. The problem comes from the computation of the lightness using the formula:

$$J = 100\left(A / A_w\right)^{cz} \qquad (1)$$

Here we must say first all the symbols used have the same meaning as in the original CIE document [1]. Li and Luo [12] showed that A_W is positive for all the popular illuminants. However, the achromatic signal A having the expression:

$$A = \left[2R'_a + G'_a + (1/20)B'_a - 0.305\right]N_{bb} \qquad (2)$$

may be negative, thus raising the negative ratio in the bracket of equation (1) to the non-integer power cz causes the early termination of the computing process.

It is believed that the source of the problem comes from the so called “yellow-blue” and “purple” problems [13-15] with a built in chromatic adaptation transform (CAT), known as CAT02. Many proposals [16-21] in the past few years have been given in the literature for solving this problem along with others. Recently, an optimum solution [22] to the “yellow-blue” and “purple” problems has been developed with the aims for solving the problems concerned with the CIECAM02 and at the same time for predicting the visual results as best as possible. The CAT is denoted CAT-OPT here. The good news is that the optimum solution not only overcomes all the problems concerned, but also has a better predicting accuracy compared with all other suggested modifications. The bad news is that the optimum solution still loses accuracy in predicting visual results compared with the original CIECAM02. All those results tell us that it is not possible we can have a new model which overcomes the concerned problems with the CIECAM02 and has the predicting accuracy as good as the original if we keep making modification using the same structure as the original CIECAM02, which motivates us to change the structure of the CIECAM02 in this study.

Objective

The purpose of this study is to modify the CIECAM02 so that the modified version not only overcomes the current concerned problems, but also gives similar degree of accuracy in predicting the visual results as the original model.

Methodology

In order to fulfill our aims, as mentioned above we have to consider the change in structure. In the original model there are two adaptations. One is the colour of the illuminant and another is the luminance of the illuminant. The two adaptations are operated in two different spaces. For the former adaptation, it is done in the so-called the CAT02 space [23] or one of the sharper sensor space [24], and the latter adaptation is done in the Hunt-Pointer-Estevez (HPE) cone space [25]. The CAT associated HPE matrix is named as CAT-HPE. Here, the two adaptations are combined to operate in a single space. By examining the original model, the main problem comes from the spectral responses in the adaptation space can be negative. So in searching the new adaptation space, the elements of the chromatic adaptation transform (CAT) matrix are modeled as variables. The non-negative spectral responses in the new space are modeled as constraints. Furthermore the row sums being to 1 should be also satisfied. Thus we have a new colour appearance model (CAM) for replacing the original CIECAM02 and at the same time, we have a new CAT. As a new CAT it should fit the corresponding colour datasets [26-32] well and as a new CAM, it should fits the colour appearance datasets [30,33-38] well. Hence, the objective function is the combinations of the colour difference between the visual results and the new CAT predictions for the corresponding datasets and the CV values between the visual results and new colour appearance model predictions for the colour appearance datasets. Thus, we end up with a constrained nonlinear optimization problem.

Results

As analyzed above we have successfully solved the constrained nonlinear optimization problem using MATLAB routine 'fmincon', resulting in a new colour appearance model named as CAM16 and a new CAT named as CAT16. The performances of the CAM16 using all colour appearance datasets and the performance of the built-in CAT16 using all corresponding datasets are evaluated respectively. All results are listed in Tables 1 and 2 respectively

Data Set	Reference illuminant	Test Illuminant	NOS	CAT02	CAT-HPE	CAT-OPT	CAT16
CSAJ	D65	A	87	4.0	5.5	5.0	4.3
Kuo	D65	A	40	5.0	6.8	6.1	5.8
Kuo	D65	TL84	41	3.5	4.9	4.7	3.8
Lam	D65	A	58	4.4	6.2	5.6	4.9
Helson	C	A	59	4.9	6.0	5.6	5.2
LUTCHI	D65	A	43	5.7	6.1	6.5	**5.6**
LUTCHI	D65	D50	44	6.6	**6.4**	**6.5**	6.6
LUTCHI	D65	WF	41	7.0	9.9	9.4	7.0
Breneman(1)	D65	A	12	7.7	8.0	**7.5**	7.7
Breneman(2)	D55	Projector	12	5.1	5.5	5.3	**4.7**
Breneman(3)	D55	Projector	12	8.2	11.1	10.9	**7.9**
Breneman(4)	D65	A	11	9.8	13.4	12.9	**9.6**
Breneman(6)	D65	A	12	7.5	**7.4**	7.6	**6.4**
Breneman(8)	D65	A	12	8.8	12.5	11.9	**8.7**
Breneman(9)	D65	A	12	14.2	18.9	18.4	**13.9**
Breneman(11)	Green	D55	12	6.6	**4.6**	**4.9**	**6.1**
Breneman(12)	Green	D55	12	7.2	**6.0**	**6.2**	**6.4**
Braun & Fairchild(1)	D65	D65	17	3.2	3.7	3.7	3.3
Braun & Fairchild(2)	D65	D65	16	5.1	5.3	5.3	**5.0**
Braun & Fairchild(3)	D65	D93	17	3.7	5.7	4.9	4.4
Braun & Fairchild(4)	D65	A	14	3.8	4.1	3.9	4.0
Overall Mean				6.3	7.5	7.3	6.3
Weighted Mean				5.5	6.8	6.5	5.6

Table 1: The prediction errors in CIELAB colour difference units for CAT02, CAT-HPE, CAT-OPT, CAT16. The values in bold in the last three columns show the corresponding CAT performs better than the original CAT02 and other values (in plain) show the opposite.

	Lightness(J)		Colorfulness(M)		Hue Composition (H)	
Group	CIECAM02	CAM16	CIECAM02	CAM16	CIECAM02	CAM16
RHL	10.6	10.7	17.8	17.2	6.9	6.4
RLL	11.4	11.5	18.6	17.3	7.1	6.7
RVL	13.3	13.3	18.4	18.5	6.5	6.7
RTE	14.8	14.8	23.7	21.8	7.1	6.9
CRT	11.6	11.6	19.6	19.8	6.7	6.6
M35	19.3	19.7	16.1	16.9	7.2	7.9
LTX	16.5	16.5	14.2	15.1	5.8	5.4
JUA	14.2	14.1	20.3	19.3	7.6	6.5
Mean	14.0	14.0	18.6	18.2	6.9	6.6

Table 2: Lightness、colorfulness and hue composition CV values for the original CIECAM02 and the CAM16 when predicting all the colour appearance datasets.

Tables 1 shows the results of CAT02, CAT-HPE, CAT-OPT and CAT16 for predicting the corresponding colour datastes respectively. In the table, the number of pairs of samples, test and reference illuminants are also listed for each corresponding data set. The performance was measured by average CIELAB colour difference between predictions of each CAT and visual results. The smaller the average colour difference is, the better the CAT performs. The overall mean and weighted mean of the averaged colour differences over all the datasets are also given in Table 1. By comparing with CAT02, the bold figures in the last three columns of the table indicate the corresponding CAT gave a better performance than the CAT02.

It can be seen from Table 1 that the CAT02 performed the best with an overall mean and weighted mean of colour difference of 6.3 and 5.5, respectively. This is expected since *CAT02* [23] was derived by fitting all the visual data sets tested. However, it is encouraging to see the newly developed CAT16 gave the almost equal performance, Thus, it can be concluded that the CAT02 and CAT16 performs equally well to predict the corresponding datasets. CAT-OPT and CAT-HPE ranked the third and the last, respectively. It is expected CAT-HPE to perform the worst since it was not derived to fit the visual datasets,. CAT-OPT was derived to satisfy some nesting rules. Overall, the key to the success to derive CAT16 is to modify the structure of CIECAM02 by combining two matrices to one.

Note that there are 21 individual datasets, the original CAT02 performed better than CAT-HPE, CAT-OPT and CAT16 over the

17, 17, 8 subsets respectively. In fact, CAT16 performed the best and it outperformed CAT02 by 10 subsets.

Table 2 shows the performances in CV measure of the CIECAM02 and CAM16 for predicting the colour appearance datasets, which are divided into visual lightness, colorfulness and hue composition data. Note that these two outperformed CIECAM02with the HPE and OPT matrices so that their results are not reported here. The results can summarized below:-

Comparing lightness predictions, there is little difference between these two CAMs with a mean CV value of 14.0.

Comparing colourfulness predictions, they gave same performance, i.e. performed equally well, in terms of subsets. However, the averaged CV value for CIECAM02 is 18.6 comparing with that of 18.2 for CAM16.

Comparing hue predictions, it is encouraging to see that CAM16 predicts more accurate in majority of subsets. There is also another important difference that CAM16 is simpler than the original CIECAM02.

Conclusion

In this paper, the CIECAM02 is modified to overcome the constrained nonlinear optimization problem. By solving the optimization problem, a new colour appearance model (CAM16) and a new chromatic adaptation transform (CAT16) are developed. CAM16 is structurally different from the original CIECAM02 and both CAT16 and CAM16 gave equal or better performance in predicting the available experimental datasets. We are glad to see after long years of research, a robust chromatic adaptation transform and a colour appearance model are finally achieved.

Acknowledgements

This research work has been supported by National Natural Science Foundation of China (Grant numbers: 61178053, 61575090)

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