Verification of MacAdam Data

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ABSTRACT

MacAdam data have been well known in the colour-difference research field. It has been used for defining the tolerance for the white lights in the lighting industry. This paper describes two separate experiments carried out at Leeds university (UK) and Zhejiang university (China) respectively. Both experiments were conducted to assess colour-differences using Eizo displays using the ratio method. Each centre included 21 samples assessed against a grey and a black background, respectively. The difference between the two experiments are the sample pair used. Leeds university had all samples selected from CIE u'v' chromaticity diagram and Zhejiang university selected from CIELAB space. These data were used to test colour difference equations and colour spaces. The result should that both present datasets disagreed with MacAdam data greatly.

KEYWORDS: MacAdam data, uniform colour space, ratio method

1. Introduction

The MacAdam ellipses[1] are plotted in Figure 1. It is one of the first sets of psychophysical data to quantify threshold of colour difference, and has been used to test the uniformity of a colour space. The data were accumulated by MacAdam in 1942 using a self-luminous visual colorimeter[1, 2]to perform colour matching experiment. Twenty-five target colour centres were made by layers of different colour films while they were illuminated by a single light source, an illuminant C simulator. The circle was separated into target and matching fields by a biprism, which were viewed monocularly. Colour matching was conducted along different lines/directions in xy chromaticity diagram surrounding the colour centre. The size of each ellipse represents the Just Noticeable Difference (JND). However, there are some drawbacks in the data. Firstly, the data were based only on a single observer and all stimuli were at one luminance level. Moreover, it is well known some drawbacks of colour matching using monocular method. The setup of the MacAdam experiment was different; and data analysis was based on the standard deviations of the colour matching assessments.

In one of our earlier studies[3], evaluation of colour difference metrics for white light sources based on the specification of the ANSI C78.377 standard was performed by assessing colour difference. The results were very promising regarding the use of u'v' chromaticity diagram for the evaluation of colour difference of lighting products. Moreover, one of the findings was that the MacAdam ellipses in close proximity to these data did not agree well. Therefore, in the current study, a set including white light stimuli from the ANSI C78.377 standard and coloured light stimuli from the MacAdam experiment were used for the acquisition of a unique dataset of colour difference assessments of lighting stimuli.

With the above in mind, the goals of this study are: 1) to study colour spaces for which samples were prepared, 2)to verify MacAdam ellipses, and 3) to test models' performance.This paper describes two separate experiments which carried out at Leeds university (UK) and Zhejiang university (ZJU) (China).

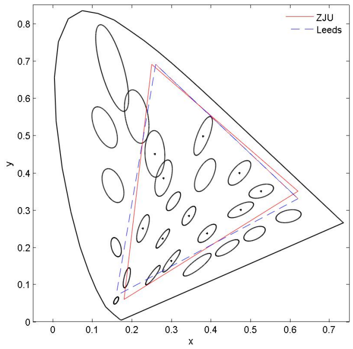


Figure 1: MacAdam ellipses. Those marked with a cross are the colour centres in the present study. The two triangles plotted in solid and dashed lines are the display gamut for the ZJU and Leeds displays，respectively.

2. Experimental

2.1 EIZO display

The experiment was performed on two EIZO CG220 displays were used for each site. The definition of correlated colour temperature (CCT) and luminance (cd/m2) for each display used. Both are close to the internal target of 6500K and 100 cd/m^2.

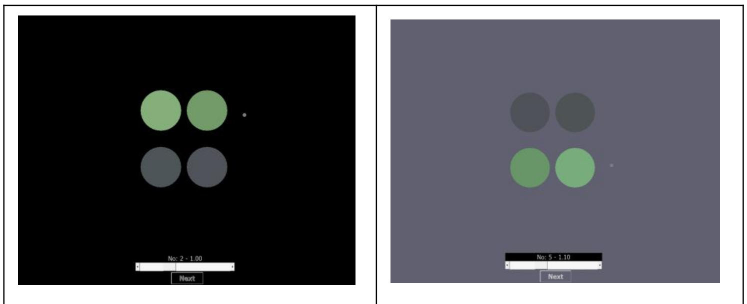
2.2 Sample preparation

Eleven colour centres were selected from the MacAdam dataset. In addition, eight neutral centres from the ANSI C78.377 standard were also included. For the 7 colour centres, all pairs to have two luminance levels, 48 and 18.5 cd/m^2.Overall, 28 colour centres were studied.For each colour centre, 21 pairs of chromatic differences were prepared. The 21 points were chosen to cover a semi-circular manner surrounding the colour centres ranging from 0^o to 180^o. The difference between each colour centre and each sample in the ellipse was defined by means of a constant chromatic distance in the colour space in question, i.e. u'v' and CIELAB a*b* planes for Leeds and ZJU studies, respectively. They corresponding to 5 ΔE^*_{ab} and 0.007 u'v' units, respectively.

Twenty normal colour vision observers took part in each site. There were 10/10 and 8/12 male/female observers for ZJU and Leeds, respectively. They had average age of 23 and 30 years old respectively. In each site, 23,520 assessments were made, i.e. (26 centres +2 repeats) x 21 pairs x 2 backgrounds x 20 observers.

2.3 Software and reference pair

The experimental arrangement of the stimuli is illustrated in Figure 2.



(a) black background	(b) grey background

Figure 2: Experimental stimuli arrangement.

Two background colours were used, a grey and a black. The latter was used to simulate light sources viewed at night. The grey background was used to reproduce the same surround field used in the MacAdam experiment.During each experiment, two pairs of stimuli were presented.Note that their location within these rows was randomly interchanged in both dimensions. The reference pair consisted of two fixed green colour stimuli ,which was set with fixed chromaticity and lightness difference ΔL^* of 6 units for both experiments. Using ratio scaling method[4], the observers evaluated whether the testing pair had a larger or smaller colour difference than that of reference pair, and reported a value larger or smaller than one accordingly. A scroll bar was provided in the software interface so as to record each assessment.

3. Inter-Observer Varability

The standardized residual sum of squares (STRESS) measure has been used widely in the colour-difference research field [5]. It is used throughout the data analysis in this study.

Table 1. STRESS values for observer uncertainty (inter-observer and intra-observer)

Name		**Inter-observer**	**Intra-observer**	**Inter-observer**	**Intra-observer**	**Inter-observer**	**Intra-observer**
	Background	Black		Grey		Both	
ZJU	Mean	24	14	25	12	26	13
Leeds	Mean	25	15	31	16	29	15

From the Table 1 results, it can be concluded that the intra-observer variability is about half of the inter-observer variability. ZJU observers performed slightly more consistent than those of Leeds observers.Observers performed slightly more consistently against the black background than those against the grey background. The STRESS values are within the same range with results of other studies[3].

4. Testing Models' Performance

Four datasets were used to test above models, ZJU, Leeds, combined datasets and MacAdam. Note that the latter was obtained by extracting the data points from each MacAdam ellipse. The combined data included both the ZJU and Leeds datasets.

Table 2 .The performance of the 6 colour models tested for each dataset in STRESS unit

Dataset	Background	**CIELAB**	**CIECAM02**	**CAM02-UCS**	**CIELUV**	**xy**	**FMC-I**
ZJU	Black	**16**	**17**	22	24	23	32
(1176 pairs)	Grey	24	21	**15**	28	28	32
Leeds	Black	28	25	30	**20**	29	26
(1176 pairs)	Grey	35	27	**24**	**23**	36	26
Combined	Black	23	**21**	26	24	26	32
(2352 pairs)	Grey	30	24	**19**	26	31	30
MacAdam (525 pairs)	Grey	43	28	30	34	51	**18**

The results can be summarized below:

1) In general, for the black background data, the models gave different performance between the ZJU and Leeds datasets. For the former, CIELAB and CIECAM02 performed better than the others. For the latter, CIELUV performed the best. This seems to be related to the space used for sampling， i.e. observers are intended to give answer in the middle.
2) For the grey background data, CAM02-UCS model performed the best for both datasets. This confirms the earlier findings that self-luminous colours display on a grey background can simulate the surface colours well. Note CAM02-UCS was designed from the surface colour data.

3) For the combined data, CAM02-UCS again consistently performed the best as expected for the grey background data. For the black background data, CIECAM02 performed the best, followed by CIELAB and CIELUV. They all predicted more accurately than the other models.
4) FMC-I is the model derived to fit the MacAdam data. It can be seen that it predicts the best to the MacAdam data but performed poorly to all the other datasets. This implies that MacAdam data have quite different characteristics comparing with the other datasets.

5. Comparing the Ellipses from Three Sets of Data

Figure 3 shows the three sets of ellipses adjusted to equal size (one scaling factor for each set).

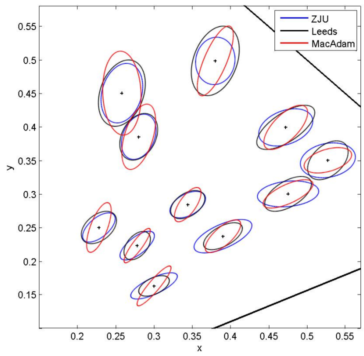


Figure 3: Comparing the three sets of ellipses.

It can be seen a clear pattern from the MacAdam ellipses in red, i.e. the size of all ellipses are increased from the smallest blue to the largest green in a radial shape. Comparing the two sets of the present data, they are similar except that the four ellipses in the bottom (from blue, purplish red, reddish purple and red) and the one in the green-yellow (top right). However, the present both sets had large disagreement with the MacAdam set. This confirms to the space testing in Table 2 why FMCI equation can only fit well to the Macadam data.

6. Conclusions

Two sets of colour difference data were accumulated at Zhejiang and Leeds universities, respectively. It was found CAM02-UCS specially used to fit the surface colour data gave the best performance for the grey background results. For the black background colours, CIELAB and CIELUV performed the best for the ZJU and Leeds datasets. This could be caused by the colour space used to sample the pairs, i.e. observers intend to estimate the results close to the middle point. Overall, MacAdam data stands out on its own. FMC-I formula fitted this data the best. However, the other models performed badly. This implies that MacAdam data behaves differently from the other datasets based on the surface and self-luminous colour.

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