Enhancing the SGCK Colour Gamut Mapping Algorithm

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Abstract

The SGCK gamut mapping algorithm suggested by CIE TC8-03 has been enhanced by introducing a two-step procedure. Firstly, SGCK is used for gamut mapping the image onto a convex hull representation of the reproduction gamut. The resulting image is then further mapped onto a more realistic representation of the reproduction gamut using hue-angle preserving minimum ΔE^*_{ab} clipping. Panel testing with fifteen test persons, six different test images, and two different printers shows that this technique gives significantly better results than SGCK.

Introduction

With the increased use of cross-media publishing, colour gamut mapping has become an area of intensive research and development. Morovič and Luo has presented a survey of research on gamut mapping showing that the field has been active since the late 70ies.[1,2] In order to facilitate comparison of the results obtained in different studies of colour gamut mapping, the CIE Technical Committee 8-03 are currently in the process of proposing a standard for how such studies should be conducted.[3]

Recently, the authors developed a tool[4] making visualisation of colour gamuts and experimentation with colour gamut mapping algorithms feasible. Using this tool, ideas for improving the SGCK gamut mapping algorithm suggested by CIE[3] were developed. In particular, preliminary experiments have indicated that the choice of gamut boundary descriptor (GBD) for the gamut mapping algorithm (GMA) is important for the final result. Another important variable is the choice of source gamut, whether it be the gamut of the source medium or the image gamut.

The purpose of this paper is to use these ideas to improve the SGCK gamut mapping algorithm, and to document the improvement experimentally. First, the experimental details are described, and then results are presented and discussed.

Experimental

Six different colour gamut mapping algorithms were chosen for the experiment. They were tested with six different sRGB images printed on two different printers. Fifteen test persons constituted the test panel, and paired comparison was used as the experimental method for comparing the results.

Algorithms

According to the CIE draft,[3] two algorithms must be included in the experiment: “Hue-angle preserving minimum ΔE^*_{ab} clipping” (Clipping) and “Chroma-dependent sigmoidal lightness mapping and cusp knee scaling” (SGCK). Based upon the preliminary experiments, six combinations of algorithms were chosen for the comparison:

1. **SGCK, image gamut:** The SGCK algorithm is used for mapping the colours of the image gamut to the reproduction gamut. Both GBDs are found using the modified convex hull algorithm proposed by Balasubramanian and Dalal[5] with an expansion factor $\gamma = 0.2$.

2. **SGCK, sRGB gamut:** Same as 1, but using the sRGB gamut as the source gamut.

3. **GAMMA, sRGB gamut:** The GAMMA algorithm[6] is used for mapping the sRGB gamut onto the reproduction gamut. The GBD for the reproduction gamut is found using the modified convex hull algorithm.

4. **Hue-angle preserving minimum ΔE^*_{ab} clipping:** This is a simple baseline algorithm which does not change in-gamut colours at all, whereas out-of-gamut colours are mapped to the closest colour on the gamut boundary in a plane with constant hue. The GBD for the reproduction gamut is found using the modified convex hull algorithm.

5. **SGCKC, image gamut:** Firstly, the image gamut is mapped onto the reproduction gamut using the SGCK algorithm. The GBD of the reproduction gamut is found using the traditional convex hull algorithm. Secondly, the resulting gamut is clipped onto the reproduction gamut using the hue-angle preserving minimum ΔE^*_{ab} clipping algorithm described above. This time, the GBD of the reproduction gamut is found using the modified convex hull algorithm.

6. **SGCKC, sRGB gamut:** Same as 5, but using the sRGB gamut as the source gamut.

Images

According to the CIE draft[3], the test images must include one obligatory test image. It is required that a minimum of three images are used for comparison. A number of optional test images are available from the committee. However, it is required that if any of the optional images are used, at least the same number of other images must be used in addition to them. Hence, we used the following set of images (see Figures 1–6):

1. **Ski:** This is the mandatory image. It was available in CIELAB colour space, relative colorimetry. The image was converted to sRGB using the sRGB profile with a perceptual rendering intent. The image contains a lot of strong colours and colour gradients.
2. **Cheshire Cat:** An Adobe Illustrator image, interpreted as an sRGB image. The image is included in order to represent typical computer graphics. It has strong saturated colours and a weak texture on the dark background.
3. **Girl:** A portrait photograph of a girl taken by a local photographer. The image contains a range of skin tones close to the sRGB border and several gradients from light to dark skin tones.
4. **Camera:** A photograph of a camera taken by a local photographer. It contains a few strong colours and a lot of details in a dark shadow.
5. **Picnic:** One of the optional CIE images. The image contains three different skin tones, grass green and sky blue.
6. **Pollution:** Another of the optional CIE images. A typical computer graphics image combining text, photographs and highly saturated diagrams.

Printers

After gamut mapping, the images were printed on two different printers. The first printer was a HP Color LaserJet 4550 PS with 80g A4 Crown Bond from Chap Paper Group. An RGB profile was made using Profilemaker 3.15 from Gretag Macbeth, and measurements were taken using Spectroscan and Spetrolino from the same company. The other printer was an Océ CPS700 with a Fiery 950c rip using 90g Kymlux paper. For this printer, a CMYK profile was generated using the same equipment. The gamuts for the two printers are shown in Figure 7.

Experimental Procedure

The viewing conditions were chosen as close to the ones described in the CIE draft[3] as possible. The images were viewed under a D50 simulator, and the room was equipped

Figure 1: The Ski image and its image gamut shown in CIELAB.

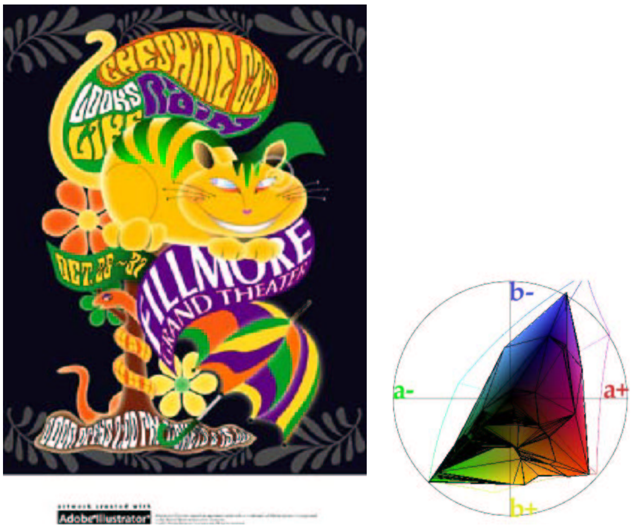

Figure 2: The Cheshire Cat image and its image gamut shown in CIELAB.

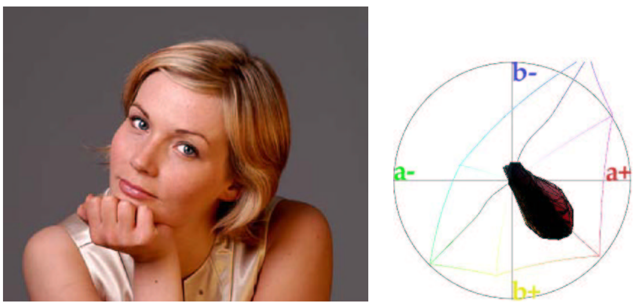

Figure 3: The Girl image and its image gamut shown in CIELAB.

Figure 4: The Camera image and its image gamut shown in CIELAB.

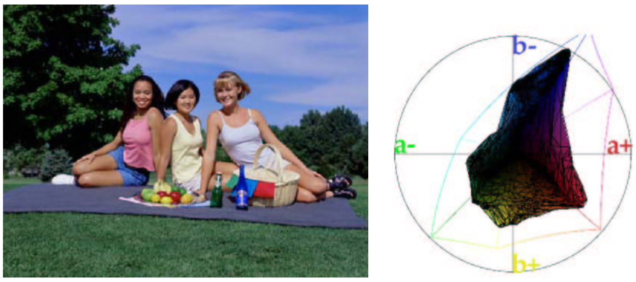

Figure 5: The Picnic image and its image gamut shown in CIELAB.

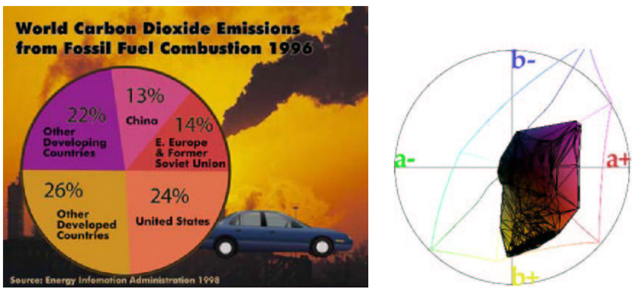

Figure 6: The Pollution image and its image gamut shown in CIELAB.

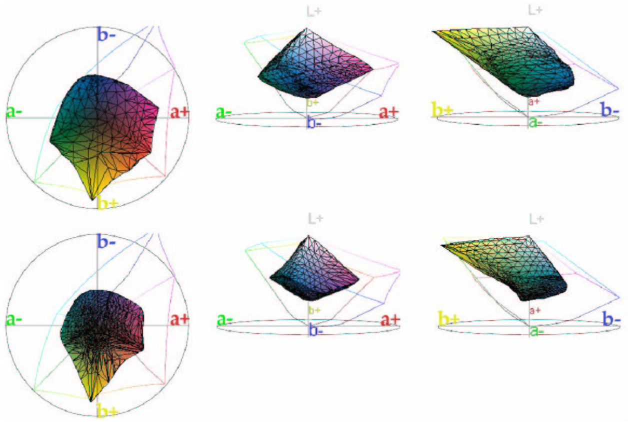

Figure 7: The colour gamuts for the HP 4550 PS (top) and the Océ CPS700 (bottom). Both gamuts are shown using relative colorimetry in CIELAB colour space, and the wireframe indicate the sRGB gamut.

with black curtains and gray walls. All coloured objects were removed, and the images were viewed under an angle of 75°. The images were surrounded with a white border of 12–24 mm on every side, and outside this border there was a large neutral 20% grey area.

The test persons were checked for colour blindness, and trained on four test images. Paired comparison was used, and every test person had to compare 180 pairs of images, meaning that the images were not compared twice. Consequently, there is a possibility for a systematic error in that some persons might prefer one side to the other when the images seem indistinguishable.

For each pair of images, the test panel was asked to indicate which of the two images they preferred. Thus, it is the pleasantness of the images which is compared, not the accuracy of reproduction. The test persons did not have access to on-screen versions of the sRGB original images, and thus no colour appearance model was used in the study.

Results

The combined results for the six images and the two printers are shown in Figure 8. The z-scores are shown in Table 1, and the total raw data in Table 2. It is evident from the figure that the SGCKC algorithms (#5 and #6) work better than SGCK alone (#1 and #2), and for algorithm #6 this is statistically significant. The present results are however not decisive as to whether the image gamut or the source gamut should be used as the initial gamut in the gamut mapping algorithm.

Results per printer

The results for each of the printers show similar trends, see Figure 9. However, for each of them, the results are not statistically significant. It is interesting to note that the differences between the algorithms tends to be bigger for the HP printer than the Océ printer, although the HP printer has

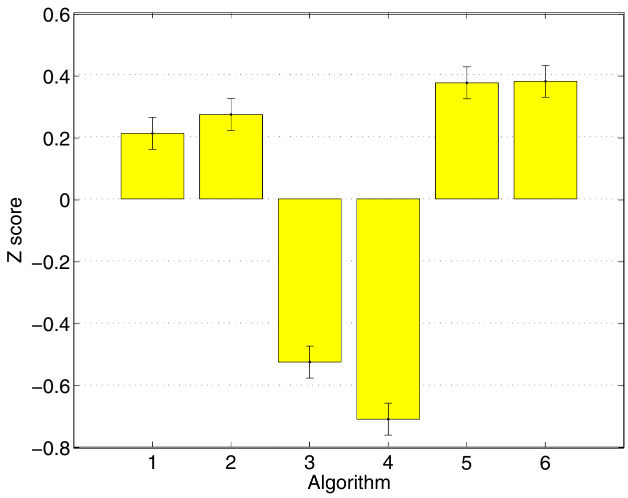

Figure 8: Combined results for the six images on the two printers. The numbers refer to the algorithms listed in the text. The figure shows the z-score and the corresponding 95% confidence interval. The proposed algorithm, SGCKC using the sRGB gamut as the source gamut (algorithm #6) performs significantly better than the original SGCK algorithm.

Table 1: Z-scores for the combined results of the two printers and the six images. The 95% confidence interval is 0.103.

Algorithm	Z-score
1	0.211
2	0.272
3	−0.526
4	−0.710
5	0.374
6	0.379

Table 2: Raw data for the combined results of the two printers and the six images.

	1	**2**	**3**	**4**	**5**	**6**
1		83	53	39	106	100
2	97		42	30	98	99
3	127	138		92	132	137
4	141	150	88		146	149
5	74	82	48	34		88
6	80	81	43	31	92	

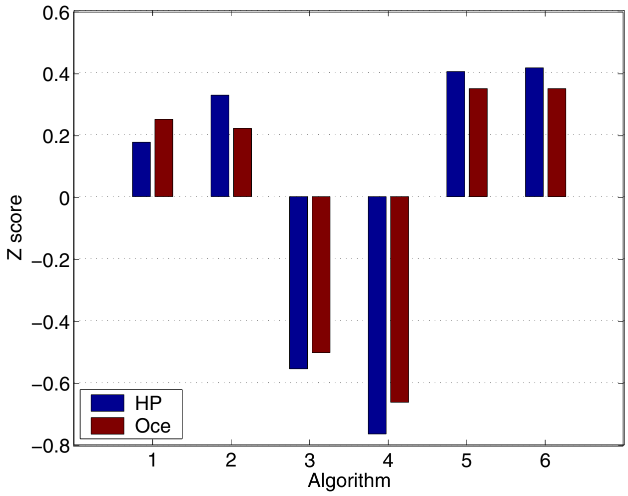

Figure 9: Z-scores for the various algorithms shown for each of the two printers. The 95% confidence interval is 0.146.

a larger colour gamut than the Océ printer.

Results for the individual images

Although the results for the individual images are generally not statistically significant, it is still instructive to study the general trends. The resulting z-scores for the individual images are shown in Figure 10 for the HP printer since the difference between the algorithms are slightly larger for this printer than for the Océ printer, as seen in the previous subsection.

1. **Ski:** For this image, there are not very large variations in the z-score, except for the GAMMA algorithm (#4) although the images look quite differently. With the GAMMA algorithm, the image is strongly desaturated, whereas with the other algorithms, the saturation is better but they contain several artefacts.

2. **Cheshire Cat:** For this image, the clipping algorithm (#4) removed the entire texture in the dark backround, whereas the GAMMA algorithm made the image desaturated. For this image there is a significant difference between the SGCK and the SGCKC algorithms, the main difference being the saturation of the foreground colours.

3. **Girl:** Again the clipping and the GAMMA algorithms perform poorly compared to the more sophisticated algorithm. For this image, it is much better to use the sRGB device gamut instead of the image gamut as the source gamut for the mapping.

4. **Camera:** For this image, all of the SGCK based algorithms perform approximately equally well, and significantly better than the the clipping and GAMMA algorithms.

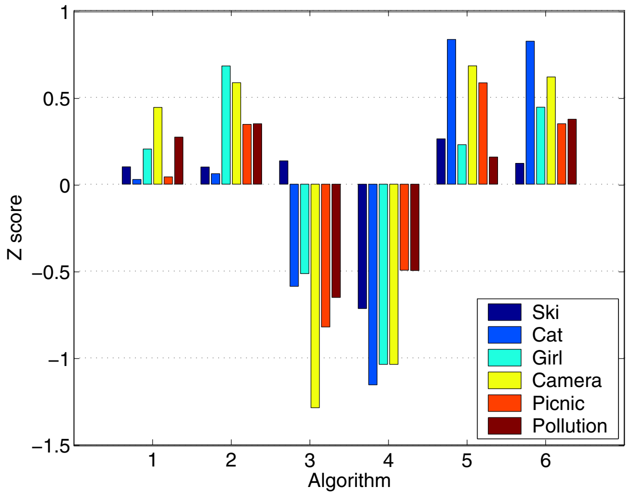

Figure 10: Z-score for the individual images for the HP printer. The 95% confidence interval is 0.346.

5. **Picnic:** For this image, the behaviour is similar to that of the camera image (above).

6. **Pollution:** Also for this image, the behavious is quite similar to that of the camera image (above). This is perhaps more surprising, since it is a very different kind of image.

Conclusions

The present study has shown that improved results with gamut mapping algorithms can be achieved by choosing different gamut boundary descriptors. In particular, the SGCK algorithm can be improved by only mapping to a convex hull representation of the reproduction gamut followed by a hue-angle preserving minimum ΔE^*_{ab} clipping. Further research on the influence of GBDs on the performance of GMAs should be undertaken.

Acknowledgements

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Biography

Ivar Farup received his M.Sc. in physics from the Norwegian University of Science and Technology in Trondheim in 1994, and a Ph.D. in applied mathematics from the University of Oslo in 2000. Since 2000, he has worked as an Associate Professor at Gjøvik University College, mainly focusing on colour imaging, image processing, and computer science.