Status of CIE Color Appearance Models

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ABSTRACT

In meetings just prior to the 1997 AIC Congress in Kyoto, CIE TC1-37, chaired by M. Fairchild, established the CIE 1997 Interim Colour Appearance Model (Simple Version), known as CIECAM97s. CIECAM97s was formally published in 1998 in CIE publication 131. CIE TC1-37 was dissolved shortly after publication of CIECAM97s at which time, a reportership, R1-24 held by M. Fairchild, was established to monitor ongoing developments in color appearance modeling and notify CIE Division 1 if it became necessary to form a new TC to consider revision or replacement of CIECAM97s. In the four years between AIC Congresses, there has been much activity, both by individual researchers and within the CIE, aimed at furthering our understanding of color appearance models and deriving improved models for consideration. The aim of this paper is to summarize these activities, report on the current status of CIE efforts on color appearance models, and suggest what the future might hold for CIE color appearance models.

1. BACKGROUND: THE FORMULATION OF CIECAM97s

The history of modern color appearance models dates back approximately 20 years to the time the earliest versions of the Hunt and Nayatani color appearance models were published.[1] It is important context to recall that these early models were suggested only about 5 years after the CIE recommendation of the CIELAB and CIELUV color spaces for color difference specification. Many fascinating and significant advances were made by Hunt, Nayatani, and many other researchers in the ensuing two decades. This work culminated in the spring of 1997 when many of these researchers converged in Kyoto and agreed upon the formulation of CIECAM97s, the first CIE color appearance model.

The formulation of CIECAM97s represents a highlight in the history of CIE (which is littered with highlights). The CIE was able to respond to the needs of the imaging industry and recommend a single color appearance model in a very short time frame (approximately 1 year from start to finish!). Perhaps most amazing, was that CIE TC1-34, which formulated the model, included members who had personally derived no fewer than eight distinct color appearance models. However, all the committee members saw the greater need and the greater good that the CIE could do and unanimously agreed on a single model that represented the best of many previously published models and could be used to focus both industrial applications and future research. Those interested in learning more about the formulation of CIECAM97s are referred to CIE publication 131,[2] a draft of which can also be obtained on the CIE TC8-01 web site.[3]

TC1-34 was under no delusion that CIECAM97s was the ultimate color appearance model, would be flawless, or would solve all problems thrown its way. However, the committee was confident that they had produced a model that performed at least as well as all previously published models across a wide variety of viewing situations. This philosophy is best indicated by the name of the model itself which includes both the word “Interim” and the date “1997”. Both were included to make it clear that it was fully expected that improvements in the model would become evident through future research and that the CIE would likely publish an updated model at some point in the future. This parallels the recommendations of CIELAB and CIELUV, which both include the date “1976” in their full designations and are both considered interim recommendations. (In fact, the CIE94 and CIE2000 color difference equations represent the result of this philosophy of continuous improvement and recognition that color science is complicated and not likely to ever be fully understood.)

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In hindsight, it is clear that CIECAM97s can be considered an unequivocal success. Not so much because it has solved all of the industrial problems with respect to color appearance (it hasn't and, in fact, no model could), but because it has successfully provided a focal point for both researchers and practitioners interested in problems of color appearance. Currently, anyone doing research and testing on color appearance models is sure to include a comparison of their results with the predictions of CIECAM97s or a comparison of suggested improvements with the original model. This focused approach to research, facilitated by the CIE's adoption of CIECAM97s, has accelerated the pace of understanding and the potential for practical solutions in color appearance to a point where significant industrial impact can be foreseen.

As soon as CIECAM97s was published, a number of studies were carried out and quickly reported that indicated areas for improvement in the model. These have been recently summarized by Fairchild.[4,3] The rapid rate at which these improvements have been formulated and reached general consensus in the field provides direct evidence of the effectiveness of CIECAM97s. These efforts have found a natural home in the activities of CIE TC8-01, which are discussed in further detail below. There are also several other CIE efforts, described in the next section, that have an impact on the formulation and use of color appearance models.

2. SOME CURRENT CIE ACTIVITIES

Ongoing CIE activities on color appearance modeling are taking place mainly within the purview of 3 active technical committees and one reportership. These are TC1-27, *Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparisons*, chaired by P. Alessi, TC1-52, *Chromatic Adaptation Transforms*, chaired by M.R. Luo, TC8-01, *Colour Appearance Modeling for Colour Management Applications*, chaired by N. Moroney, and R1-24, *Colour Appearance Models*, M. Fairchild.

TC1-27 is in the process of completing a final round of visual experiments designed to evaluate the performance of various color appearance models (including CIECAM97s and suggested improvements) for cross-media color reproduction applications. Results of earlier experiments confirmed the expectations of TC1-34 that CIECAM97s would work at least as well as the best-performing models in each type of experiment. It should, however, be noted that other models often perform as well as CIECAM97s. These experiments have also served very well to help clarify the difficulties in understanding and predicting the effects of surround relative luminance levels on the perceived lightness contrast of images. While the effects are well known, predicting their magnitude is extremely complex and depends on variables such as the image field of view, observer task, image content, *etc.* It is anticipated that TC1-27 will wrap up its work in the very near future.

TC1-52 was established with the goal of recommending a CIE chromatic adaptation transform. Chromatic adaptation transforms are one component of color appearance models, but often find use independent from the full appearance models. For example, chromatic adaptation transforms are often used in the calculation of indices of metamerism or in simple white-point transformations for image reproduction. To date, TC1-52 has been unable to agree upon a single adaptation transform for recommendation. This is because there are several transforms that have been proposed with similar predictive performance. It should also be noted that the performance of these transforms is not significantly different from the performance of the transform incorporated into CIECAM97s when the uncertainty in the visual data is considered. While it was hoped that TC1-52 would come to a conclusion consistent with the recommendations of TC1-34, the inability to do so has been productive in highlighting potential revisions and simplifications of CIECAM97s model. This result provides hope for the future possibility of consistent CIE recommendations for a chromatic adaptation transform and a color appearance model. It is apparent that TC8-01 will recommend a revision to CIECAM97s with a simplified chromatic adaptation transform. Perhaps this result will provide some useful data for TC1-52.

TC8-01 is working to make CIECAM97s useful in practical imaging applications. As part of this endeavor, TC8-01 has been examining possible corrections, refinements, and simplifications of the model. These range from a few simple changes to the model to logically improve its performance to reformulation of the embedded chromatic adaptation transform and chroma scale. The main objective in considering modifications to the model has been to make it more useful in practical applications while improving, or at least not changing, the model's performance. The committee

seems to be coming to a consensus on the general structure of changes to be proposed and is currently working on formulating a detailed recommendation. A review of many of these proposed revisions and a general structure for a revised model have been summarized in a paper prepared for TC8-01 and recently accepted for publication in Color Research and Application.[4,3] In addition, Hunt *et al.* have recently suggested additional refinements for model reformulations.[5,3] It is likely that TC8-01 will suggest a revised model that includes aspects of both of these proposals (which are more similar than different). The following section of this paper provides some more details on the proposed revisions to CIECAM97s and the outlook for their adoption.

Finally, R1-24 continues to collect information on activities in the area of color appearance modeling and report them to Division 1. At this point in time, all of the relevant activities seem to be under consideration of the various TCs mentioned above. If and when the time arises, R1-24 will make a recommendation to Division 1 to form a new committee to consider revision of the CIECAM97s model. One important consideration in this activity will be an effort to assure that any model proposed by Division 8, through TC8-01, is consistent with future recommendations from Division 1. This paper can be considered one of the activities of R1-24.

3. REVISION OF CIECAM97s

As part of its activities, CIE TC8-01 has begun the process of preparing a revision of CIECAM97s to address a number of known flaws, include improvements, and enhance usability in practical applications. A number of such improvements have been suggested by various researchers. At the meeting of TC8-01 in April, 2000, it was decided that many of these suggestions had reached a level of consensus that would allow the task of formulating a revised model to begin. All of the agreed upon revisions along with a few additional suggestions were collected in a single paper to facilitate the work of TC8-01.[4,3]

Among the most important of the revisions discussed was the simplification of the chromatic adaptation transform embedded within CIECAM97s. CIECAM97s includes a modified form of the Bradford chromatic adaptation transform that is similar to a simple von Kries scaling for the red and green channels, but includes an adptation-level-dependent nonlinearity on the blue channel. The form of this nonlinearity renders exact inversion of CIECAM97s (a necessity for many applications such as color reproduction) impossible and makes even approximate inversion difficult. A number of researchers (including Li, Luo, Fairchild, Süsstrunk, Finlayson, *et al.;* see ref. 4) have found that the nonlinearity in the chromatic adaptation transform can be eliminated without adversely affecting model performance (and in some cases improving it) as long as the matrix transformation from XYZ to RGB was also optimized. Including such a linear chromatic adaptation transform (essentially a von Kries transform) in a revised color appearance model would make it significantly easier to use in many situations and is seen as a major advantage. CIE TC8-01 agreed that such a linear adaptation transform should be included in a revision, but is still working to decide exactly which of several proposed XYZ-to-RGB transformation matrices to utilize. It is worth noting that all of the proposed models are capable of predicting available visual data on chromatic adaptation to within experimental uncertainty. The various proposed matrices are discussed and compared in references 4 and 5, drafts of which can be found at reference 3.

Fairchild[4] summarized the proposals for revision of CIECAM97s that were discussed within TC8-01 and proposed a revised model as a starting point for the committee's work. The changes suggested include:

1. Linearized Chromatic Adaptation Transform,
2. Correction of Anomalous Surround Compensation,
3. Correction of Lightness Scale for Perfect Black Stimuli,
4. Correction of Chroma-Scale Expansion for Low-Chroma Stimuli, and
5. Formulation of Continuously-Variable Surround Compensation.

At the time this paper was written it appears clear that items 1, 2, 3, and 5 from the list above will be included in any proposed model generated by TC8-01. However, the precise formulation of the linear adaptation transform is still a

topic of discussion. Item 4 has found support from a few distinct studies and has a reasonable chance of being included in a revised model.

Hunt *et al.* recently suggested further changes in a paper that has been submitted to *Color Research and Application*[5] and also distributed to TC8-01.[3] In it, they suggest adoption of items 1, 2, 3, and 5 with a few slight changes in the specific constants used. In addition, they propose revised predictors of chroma, colorfulness, and saturation. At this time, it is unclear whether these additional proposals will be included in a TC8-01 model, however they will be thoroughly considered. It should be noted that the Hunt *et al*. chroma scale is inconsistent with item 4 in the above list, so a decision on which form to follow will have to be made within TC8-01. However, rather than focusing on the one significant difference, it is important to point out that most of the substance of the proposed changes has been agreed upon and the potential for TC8-01 to be able to work out the fine details and produce a useful, and significantly improved, revision of CIECAM97s is very high.

Currently a subgroup of TC8-01, led by committee chair N. Moroney, is in the process of working through all of the proposed revisions to come up with a single formulation to suggest for committee, and ultimately CIE, approval. At the time of this writing it is impossible to predict the precise formulation of this model. The committee's plans call for discussions of the revisions during meetings after the AIC congress in Rochester in June 2001 with a draft model prepared by autumn, 2001. If all goes well, and CIE divisions 1 and 8 ratify this work, it is entirely feasible that the world will see CIECAM01s (or maybe CIECAM02s) in the very near future. Such a happy event will only serve to improve color appearance research and applications in the years to come.

4. FUTURE DIRECTIONS

As suggested in the previous section, reporter R1-24 (also the author of this paper) will suggest to Div 1. that the model to be proposed by TC8-01 be considered a revision of the CIE interim color appearance model and not a separate entity. In so doing, this is equivalent to suggesting that TC8-01 be given the charter to author what likely will become the CIECAM01s to avoid any possible confusion. It is worth noting that the comprehensive version of the model, to be designated CIECAM97c, was never formulated and appears not to be an urgent need. However, it is suggested that the "s" and "c" designations be retained since a more comprehensive model might become necessary in the future.

The CIECAM97s model has been successful in focusing research and development activities on a single model. This focus has allowed for significant new gains in knowledge over the past four years. As originally intended, CIECAM97s is an interim model and it is becoming increasingly clear that consensus will soon be reached on several evolutionary improvements to the model that also make it easier to use. With this in mind, there is reason to be optimistice about the publication a new version of the CIECAM*XX*s model in the coming years.

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