CIE Division 1 Liaison Report to Division 8

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The Division held a very successful meeting at the National Physical Laboratory, Teddington, UK, in April 2000 and this report represents the outcome of that meeting. Only the activities of the committees in the Colour Section are reported here: those interested in the Vision Section are referred to the latest Activity Report on the CIE website.

TECHNICAL COMMITTEES

TC1-27 Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparison

Paula Alessi US

Terms of Reference:
To study and make recommendations for the specification of a colour appearance match between a reflective image and a self-luminous display image.

Working Programme:
1. Investigate whether the CIELUV and CIELAB colour spaces adequately specify a colour appearance match between a reflective image and a self-luminous display image.
2. Investigate whether modifications to the CIELUV and CIELAB equations (such as white object point colour stimulus specification) would be adequate to specify a colour appearance match between a reflective image and a self-luminous display image.
3. Investigate the use of the Hunt and Nayatani colour appearance models to specify a colour appearance between a reflective image and a self-luminous display image.

Report:
Phase one of the three final experiments has been completed. This phase featured 8" x 10" prints viewed in a room illuminated with CIE D50 simulators at a viewing distance of 21" and softcopy 8" x 10" matching images on a CRT set to a 9300K white point, also viewed at a distance of 21". The luminance level for both hardcopy and softcopy white points was 70cd/m^2.

The hardcopy prints and a large colour patch set were scanned and a model was derived from the colour patch set to reliably convert from scanner code value to XYZ. This model was used to convert scanned print data to XYZ. Then softcopy matching images were created to the print XYZ data on a pixel-by-pixel basis. The following uniform colour space, chromatic adaptation transforms and colour appearance models were used for making the matching softcopy images: CIELAB, von Kries, Bradford (D computed), Bradford (D set = 1.0), Nayatani '97, Hunt '96 (assuming average surround), CIECAM97s (assuming average surround), LLAB (assuming
dim surround) and RLAB (assuming dim surround). The surround choices came from the results of a pilot study. The prints were gamut-compressed so that no softcopy matching image for any of the models contained pixels outside of the video gamut. Finally the prints were made less sharp in an attempt to match the perceived sharpness of the softcopy matching images.

A psychophysical experiment was run featuring the memory-matching technique across media. A forced choice paired comparison experiment was run where 30 observers saw 36 pairs (i.e. all possible pair combinations of 9 models) of softcopy matching images for each of four scenes (Barn, Golfer, Musicians, and U-chart). Each observer adapted to the print for at least 60 seconds. (The prints had a 1/4" white border and then they were mounted on an 18% gray board.) The room lights were turned off and the observer adapted to an 18% gray on the CRT for 60 seconds. Then the pairs were presented. (The CRT images were just like the prints in that they were surrounded by a 1/4" white border and then a larger gray border that filled out the CRT raster.) The observer was asked to pick which member of the pair best matched the print they just saw. Observers were allowed to look back at the print at any time recognizing that they would have to go through the adaptation periods again. If an observer did not request to look back at the print by pair 12 or pair 24, they were asked to do so. The following model ranking results were obtained from a Duncan test of statistical significance:

Barn:
CIELAB < Nay'97 < RLAB < vonKries = LLAB < Brad(D=1) < Hunt'96 < CIECAM97s < Brad

Golfer:
CIELAB < RLAB < Nay'97 < vonKries < LLAB < Hunt'96 < Brad(D=1) < CIECAM97s = Brad

Musicians:
Nay'97 < RLAB < CIELAB < LLAB < vonKries < Brad(D=1.0) < Hunt'96 < CIECAM97s < Brad

U-chart:
Nay'97 < CIELAB < RLAB < LLAB < Hunt'96 < vonKries = Brad(D=1) < CIECAM97s < Brad

These model ranking results were substantiated by other tests of statistical significance like the Bradley-Terry method and the Scheffe method.

It is clear that for all four scenes, the top two models were Bradford and CIECAM97s. In fact, Bradford was the top model for all scenes, except golfer, where it came out equal to CIECAM97s. These are not surprising results. The media differed only in chromaticity (i.e. print white point at simulated CIE D50 and CRT white point at 9300K and both at 70cd/m^2) so one might expect that a chromatic adaptation transform like Bradford would be all that is necessary to achieve equal colour appearance across media. It is worth noting that CIECAM97s uses the Bradford chromatic adaptation model, which is probably why it also scored high. It is also worth noting that both versions of the Bradford model always outscored the von Kries chromatic adaptation model. Also Bradford with D computed always outscored Bradford with D set to 1.0. The poorest performing models were CIELAB, Nayatani'97 and RLAB(dim surround).

The next step is to use the same experimental approach on the second set of viewing conditions, which features the print white point at simulated CIE D50 and 600cd/m^2 with the CRT white point at 9300K and 70cd/m^2. Based on the results from the first set of viewing conditions reported above, it is proposed to drop CIELAB, Nayatani'97 and Bradford (D=1.0). Also CIECAM97s2 will be used instead of CIECAM97s and the new Nayatani et al. model known as CIECAT94LAB. Thus the model list would be the following: von Kries, Bradford, Hunt'96, RLAB, LLAB, CIECAM97s2, CIECAT94LAB. A new set of scenes will be used to overcome some problems with the previous set. Another pilot experiment will have to be performed to determine the proper surround conditions for Hunt'96, RLAB, LLAB, and CIECAM97s2.

TC1-38 Compatibility of Tabular Data for Computational Purposes
Cal McCamy

Terms of Reference:
To prepare guidelines for tabulating CIE spectral data to provide compatibility of sets of data for computational purposes, considering such factors as spectral range, spectral interval, function, truncations, interpolation, extrapolation and number of digits.

Report:
The third draft of a CIE Technical Report *Recommended Practice for Tabulating Spectral Data for Use in Colour Computations* was prepared and distributed for comment. Dr. Sève of France agreed in general with the proposals and provided editorial comments and a careful mathematical analysis. A fourth draft is being written to take these contributions into account. The committee has given a great amount attention to methods of interpolation. It appears that we are reaching consensus in that regard. One objective of the technical committee is to recommend the spectral interval between tabulated values. The recommendations were virtually unchanged from the first to the second and from the second to the third draft and in the latest round, only minor editorial clarification and nothing substantive was suggested. The proposed wording of the fourth draft is as follows:

It is recommended that spectral data for use in colorimetry be standardised at 5 nm intervals.

It is recommended that the definitive values of colorimetric quantities be those based on computations at 1 run intervals, with values of colorimetric functions and standard illuminants being interpolated at 1 nm intervals, by the recommended method, and values of the spectral modulation of objects or spectral power of lights being measured at 1 nm intervals. Given a recommended method of interpolation, colorimetric functions and standard illuminants need not be published at 1 nm intervals.

In the past year. TC1-48 has had to consider the issue of spectral intervals. Dr. Schanda. Chairman, has obtained broad participation and members have contributed a great deal. Whereas TC1-38 addressed spectral intervals in the abstract. TC1-48 had to address specific cases in the revision of Publication 15. With specific cases, they were able to compute errors associated with different approaches. In formulating the recommendations of TC 1-38 for future applications, we shall take full advantage of the results of computations, the experience brought to bear, and the insights gained by the well-organized and vigorous debate in TC1-48.

TC1-44 Practical Daylight Sources for Colorimetry
Robert Hirschler BR

Terms of Reference:
1. To inter-compare existing daylight simulators for colour measuring instruments and colour matching booths
2. On the basis of this inter-comparison, to recommend practical methods for simulating daylight sources.

Working Programme:
1. Obtain spectral irradiance data on existing simulators for both colour-matching booths and colour measuring instruments, either directly from the manufacturer or from spectroradiometric measurements performed by the committee members, under standardized conditions.
2. Evaluate the performance of these existing simulators according to various criteria, including: 1.) quality of simulation based on CIE Publication no.51; 2.) integrity of

simulation (e.g. stability, insensitivity to instrument geometry and polarization effects, optical throughput); 3.) practicality of implementation (e.g. simplicity of fabrication, economy, compatibility with existing instrumentation)

3. Prepare a CIE technical report on these findings and provide recommendations for practical methods of simulating daylight sources for different applications (e.g. based on allowable colour-difference errors). It is expected that more than one method will be required to satisfy practical considerations. This is likely because, for example, it is not possible to have as stable or reproducible a daylight simulation with pulsed lamps as continuum lamps, but they are preferred for on-line measurements; so this reality must be accommodated in the recommendations.

Report:
No report received.

TC1-47 Hue and Lightness Correction to Industrial Colour Difference Evaluation
Dave Alman US

Terms of Reference:
To investigate the hue and lightness dependence of industrial colour difference evaluation using existing experimental data.

Report:
This committee met at NPL. Subcommittees of TC1-47 reported proposed corrections to the CIE94 industrial colour-difference evaluation model for hue angle dependence of hue difference, lightness dependence of lightness difference, interaction of hue difference and chroma difference for blue colours and chromatic non-uniformity of neutral colours. The proposed corrections have been extensively tested with several visual colour-difference data sets. The working programme of TC1-47 will now move from the investigation to the report phase and recommend a new colour-difference formula.

TC1-48 Revision of CIE Document 15.2 Colorimetry
Janos Schanda HU

Terms of Reference:
To produce a revised edition of CIE Document 15.2 taking into consideration other relevant CIE recommendations

Report:
Work is well in hand and, following a meeting of the TC at NPL a final draft will be produced. It has been decided that it will be recommended that colorimetry be performed using 1 nm data as provided by the CIE/ISO standards. Recommended methods will be given to enable data to be interpolated to 1 nm and also to enable calculations to be performed using other wavelength intervals. Correlated colour temperature will be defined using a mathematical function in such a way that the results will be the same as those obtained by the present method. A new series of lamp spectral power distributions will be provided, in addition to some of those already in Document 15.2.

TC1-52 Chromatic Adaptation Transform
Ronnier Luo GB

Terms of Reference:
To review the chromatic adaptation transforms with a view to make a recommendation.

Report:
This TC met at NPL and it has been agreed that a technical report will be produced describing available methods for predicting corresponding colours. It is not possible to recommend a single method at this time.

TC1-53 A Standard Method of Assessing the Quality of Daylight Simulators
Cal McCamy US

Terms of Reference:
To prepare a CIE Standard for the assessment of daylight simulators.

Report:
Draft 3 of a proposed CIE standard method of assessing daylight simulators was submitted to a letter ballot of the members of the technical committee on November 13, 1999. The draft received full approval, but with numerous comments. All of the recommended changes were incorporated in the 4th draft, dated January 9, 2000. There were numerous changes in terminology. A copy of the draft was sent to Dr. Pointer, because of his involvement with terminology. There were so many changes, some a little beyond editorial in nature, that it was considered appropriate to give the members an opportunity to approve the draft or make further comments. Responses were requested before the end of March. Because of the extensive involvement of fluorescence in the method, it is important to coordinate this effort with TC2-25. Its chairman, Dr. Joanne Zwinkels, is a member of TC1-53. There has been only one response as of this date, with full approval and no comment. As soon as the remaining responses have been received, the Division will be apprised of the status of the work.

TC1-55 Uniform Colour Space for Industrial Colour Difference Evaluation
Jim Nobbs UK

Terms of Reference:
To devise a new uniform colour space for industrial colour-difference evaluation using existing experimental data.

Report:
This TC met informally at NPL and has formulated a working programme that will investigate various approaches to solving the problem.

TC1-56 Improved Colour Matching Functions
Mike Brill US

Terms of Reference:
1. To compare results based on the current CIE colour matching functions, colour matching functions proposed by Dr. W. Thornton's laboratory, and those of CIE TC1-36.
2. To initiate experiments to obtain data for such comparison in different laboratories.
3. To report to CIE Division 1 on the results of the above investigation and make an eventual recommendation for future CIE colour matching functions.
4. To report to CIE Division 1 an eventual recommendation for the use of the new colour matching functions in specifying colour spaces and colour-difference formulas.

Report:
The present report is to inaugurate the work of the new CIE Technical Committee TC1-56. Over the past month the Committee has discussed the document by email, so the report is the output of a virtual meeting that replaces the originally scheduled face-to-face meeting at

NPL. Although some members are interested in exploring particular questions in more detail than indicated here, this report comprises a consensus of the work plan.

1. Introduction

TC1-56 has the charter to examine the fundamentals of colorimetry in view of some recent, empirically based questions. Even now, this effort is perceived as very important for the future of colorimetry. A precondition to the terms of reference is to set to rest a problem noted by W. A. Thornton (*Toward a more accurate and extensible colorimetry, Parts I-III*, Color Research and Application. Vol. 17, 79-122; 162-186, 240-262, 1992). Thornton found experimentally that colour-matching functions for a single observer do not transform appropriately to predict colour matches by the same observer using another set of primaries. Additional experimental evidence will be sought that bears on this question of transformability. Although extending a little beyond the terms of reference, it may be useful to discuss how (if at all) a new set of colour-matching functions should be retrofit to existing colour difference and colour appearance models.

Some of the issues to be addressed by the present committee were discussed at a symposium sponsored by the CIE in June, 1993 on Improved Colorimetry (Proceedings are in CIE Publication x007). Although a review article on these matters may not exist, several researchers at that Symposium pointed to failures of colour-match additivity (due to rod intrusion, due to photo-pigment depletion, etc.), and failure of the CIE colour-matching functions (either 2-degree or 10-degree variety) to capture the entire population of human observers' colour matches. The question remains open as to whether these failures create important impediments to practical applications of the colour-matching functions (e.g., inter-device matching that involves colour matching of lights with large spectral mismatches). Thornton may be unique in offering evidence of very large and fundamental failures of the existing colour-matching formalism.

For the next four years, TC1-56 will look at these issues with due deliberation. In the eight years since Thornton's original papers, the crucial experiments have not been repeated. A major objective of TC1-56 is to rectify this omission. Any technical decisions based on the one negative result must await corroboration, especially in view of the success of the CIE system in certain venues.

2. Beginnings of a Work Plan.

Based on the above background and terms of reference, here is a possible work plan for TC1-56. The work plan encompasses experiments, data analysis, and recommendations concerning several questions. The questions, outlined below, might well be addressed in parallel by interested subcommittees of TC1-56.

2.1. For a single human observer, are colour-matching specifications amenable to transformation of primaries? This question is of critical importance, because transformation of primaries is tantamount to two applications of Grassmann's additivity law. (Find the Set-2 match of each primary in Set 1, replace each Set-1 primary with its Set-2 match, and thereby predict the matches made with Set 2 in a new experiment.) Hence Grassmann additivity fails if transformability fails.

Accordingly, a laboratory is needed to conduct the following experimental program:

a. Acquire a proven apparatus for measuring colour matches, including a spectroradiometer to measure the lights participating in the matches, a monochromator that can traverse the visible spectrum and produce reliable colour-matching functions at 10 nm intervals, a bipartite 10-degree field (binocularly viewed) in which to display (at high photopic light levels) the two halves of the match. The radiometer should calibrated to a suitable standard

lamp. To be sure of the retinal illumination, one may use special apparatus to measure pupil diameter, or light levels may be high enough to use an artificial pupil.

b. Screen from 6 to 10 subjects using Ishihara and Farnsworth tests for normal colour perception. At least two of the subjects should be less than 30 years old, at least two should be between 30 and 50 years old, and at least two should be over 50 years old.

c. Select two sets of wavelengths for the primary-light sets. To replicate Thornton's experiment, the wavelengths 452, 533, and 607 nm might comprise Set I, and the wavelengths 497, 579, and 653 nm might comprise Set 2. (A third set, at wavelengths 477, 558, and 638 nm, might be used if time permits.) The primary sets must be very different from each other in their selected wavelengths.

d. Perform maximum-saturation matches to develop colour-matching functions (cmf's) for each observer and for each primary set. If time permits, perform the corresponding Maxwell colour matches.

e. Repeat Step d enough times on each subject to obtain a statistically significant estimate of intra-observer variability. Then, average the results within each given subject/primary-set to obtain colour-matching functions.

f. For each subject, perform a transformation from Set-1 cmf's to predicted functions from Set-2 primaries.. Compare these predicted functions to the Set-2 functions obtained directly by experiment.

NOTE: It may be sufficient for the transformability experiment to measure the colour-matching functions at only a few wavelengths besides those of the primaries.

A background theoretical task might be to perfect the data analysis and computation of colour-matching functions so as to avoid the problems noted by Thornton.

2.2. What set of colour-matching functions best represents (up to linear transformation) the population of colour-normal human observers? Several sub-issues need to be settled:
a. Should observer data be averaged prior to transformation to a desired basis set, or afterward?

b. What data sets should be examined? (Examples are the Stiles-Burch set used by TC1-36 and available in Wyszecki and Stiles, *Color Science*; the results from Thornton's laboratory, and others such as emerge from the facility performing phase 2.1 of the effort.)

c. Which, if any of the Standard Observers are sufficiently close to the data to be chosen as the "best"? Example Observers are the CIE 10-degree and 2-degree Standard Observers, and the Judd-modified Standard Observers.

d. What should be the recommended "best set" of colour-matching functions?

e. How should observer variability be characterised by the CIE?

f. What are the ramifications of observer variability in practical colour technology?

To resolve these issues, the experience of the committee members and published experiments may go a long way. However, new observer-variability studies may be

suggested as the program proceeds, as field trials for the various suggested Standard Observers.

2.3. How shall quantities that have been derived from colour-matching functions in the past be modified in the event of new colour-matching functions? This question may not be answerable definitively within the scope of the committee, but should be discussed in order to provide a suggested recommendation to the CIE.

3. Next Steps.
At least one laboratory must sign up for the experiment in Section 2.1. That laboratory must have the equivalent of a high-precision visual colorimeter. Comments and volunteers are solicited. As motivation, it should be kept in mind that numerous queries from other standards bodies and industry have already been directed at TC1-56 even before its work is started. The world is waiting for an answer from us.

To participate in discussions, please email the email of the Chair of the committee, Mike Brill, at mbrill@sarnoff.com.

REPORTERS

R1-11 Cognitive Aspects of Colour: G Derefeldt SE

Report:
The manuscript for this report has been prepared and was given to the Division Editor at the meeting at NPL.

R1-15 Lighting Terminology: M. Pointer GB

Terms of Reference:
To provide liaison between Division 1 and TC7-06 'International Lighting Vocabulary' and support the preparation of a new edition of the 'Lighting Vocabulary'.

Report:
The final revised versions of Sections 2 and 3 of the International Lighting Vocabulary were submitted to the CIE Central Bureau at the end of August 1999 and have now been balloted by national committees. Many comments have been received and these will now be addressed.

R1-18 The Use of Colour Identification under Various Illuminance Levels: T Ishida JP

Terms of Reference:
1. To survey the state-of-the-art of colour codes under various illuminance levels
2. To judge whether the CIE should establish a Technical Committee on this topic
3. To establish liaisons with CIE Divisions 3 and 4.

Report:
A survey of the related studies was reported in Warsaw and this work is continuing.

R1-24 Colour Appearance Models M Fairchild US

Terms of Reference:
To monitor the progress and development of colour appearance models.

Report:
There has been some recent research activity in the area of colour appearance models to be reported to the CIE. However, all of the important issues raised are currently being addressed by CIE technical committees, thus there is no need to form another committee at this time. This reportership will continue to monitor activity and welcomes input.

Revision of CIECAM97s
Three general suggestions have been made for improvement of CIECAM97s. Two are relatively minor formal revisions that were discussed within TC8-01 and reported by Li et al. (7th IS&T Color Imaging Conference and forthcoming in Color Research & Application) that correct practical issues with the lightness scale and surround compensations. The third is a new formulation of the chromatic adaptation transform to eliminate the nonlinearity that causes complications when inverting CIECAM97s. Finlayson and Susstrunk will describe this work at the Derby conference in April. Complimentary work is also ongoing at RIT. It is expected that CIE TC8-01 will consider these revisions and make recommendations.

Chromatic Adaptation Transform
TC1-52 is completing more tests of chromatic adaptation transforms and thus far the data support the formulation in CIECAM97s. This is a nice confirmation of CIECAM97s.

Other
A variety of other papers testing colour appearance models and applications have been published. Much has been learned to date. Thus far, no results have suggested that CIECCAM97s is not at least among the best models evaluated. This is consistent with the testing available in 1997 when the model was formulated. This research will be summarised in a more formal report from R1-24 at a future date.

R1-25 Liaison with ISO/TC35: Paint and Varnishes Colorimetry K Witt DE

Terms of Reference:
To cooperate with ISO/TC35 in their production of a series of ISO standards for the colorimetry of paints and varnishes.

Report:
The new chairman of ISO/TC 35: Paint and Varnishes is Dr. G. Etzrodt from BASF, Ludwigshafen and the new secretary is Mr. B. Reinmuller from DIN. Both were informed about the problems with copyright of CIE publications used in ISO standards. I had a first very co-operative meeting with them on March 8, 2000 in Berlin at DIN. We discussed the status of the series of colorimetric standards ISO 7724, and what could be done to improve the link to CIE. The following procedure was proposed:

a. ISO shall be asked to agree on the introduction of CIE/ISO standards.
b. The responsibility of CIE is to formulate colorimetric standards deduced from Publication 15.3. The drafting procedure should include ISO/TC 35 activities as well as those of other relevant ISO Committees
c. ISO desire to reduce the number of standards could lead to a reformulation of the ISO 7724/1-3 series.
d. CIE should formulate a first draft of a CIE/ISO 7724 standard "colorimetry" as a collation of the three parts directly deduced from Publication 15.3. I accepted to try a first draft based on the existing data files of the ISO 7724 series by May 11.
e. The standard shall meet the needs of the colorant industries.
f. Colorimetric tables should be omitted in favour of those in the original CIE publication.

g. Dr. Etzrodt shall put the new activity on the agenda of the forthcoming ISO/TC 35 meeting June 2000 in Oslo.
h. The drafting procedure of CIE and ISO should be done in close connection. The final voting on the standards must be started in CIE and finalised by ISO allowing only a "yes/no" answer.

I was informed about the results of a further meeting between Dr. Etzrodt and colorimetric experts from BASF (Dr. Gall, Mr. Unterforsthuber). Their idea is to formulate the new standard as the standard of basic colorimetry and to add further standards on applications that focus on sample preparation and formulae with only cross reference to the CIE colorimetric standard. The colorimetric standard should include:

a. Calculation of tristimulus values optionally including tables of colour matching functions and illuminants, definitions of start and end wavelength and step width of spectral data and of an algorithm how to process data of different step widths, and how to proceed with subtraction of "gloss".
b. Measuring procedure including calibration, reference standards, geometries, poly-chromatic or monochromatic illumination, nomenclature of measured values, fluorescence, transmission.
c. Colour co-ordinates, colour differences (CIELAB, CIELUV, CIE94 (DIN99?)), CMC etc.
d. Other colorimetric entities such as depth of shade, hue of near white colours, whiteness, yellowness index, metamerism index.

We must decide what CIE can do and what must be left to ISO for further standardisation. I hope to receive a clear answer for the ISO secretariate so that it may formulate an agenda for the forthcoming ISO/TC 35 meeting in consensus with CIE.

R1-26 CIE Encyclopaedia on Colour - P Walraven NL
Terms of Reference:
To investigate the feasibility of producing an encyclopaedia on Colour as a CIE publication. The study should include the consequences of a publication by CIE, being its own publisher, and of a publication by CIE in cooperation with a well-known publisher.

Report:
Negotiations with Wiley are continuing. A discussion with the Publications Board of CIE has taken place during the symposium on the 75th Anniversary of CIE 1924 V(l) regarding the format of the publication. It is essential that the publication should be in the framework of the publication-strategy of CIE. This will be further negotiated with Wiley.

NEW WORK

TC1-57 Standards in Colorimetry
Terms of Reference:
To prepare a series of CIE/ISO/IEC Standards that describe:

1. The method of calculating CIE tristimulus values and chromaticity coordinates

2. A uniform colour space and its associated metrics
3. A formula for industrial colour difference evaluation

Chairman: Mike Pointer
Members volunteered at the D1 meeting: Dave McDowell, Klaus Witt, Dr Yaguchi, Janos Schanda, Peter McGinley

Two other new committees were formed for the Vision Section: TC 1-58 Visual Performance in the Mesopic Range (Julie Taylor) and TC 1-59 Standard Photometric 10 degree Observer (Janos Schanda).