State of the art in colour science and technology

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ABSTRACT

A review of the scientific papers of the Congress AIC2005 is given.

1. INTRODUCTION

The oral papers and poster papers of the 10th Congress of the International Colour Association held at Granada, Spain, in May 2005 given for the area of colour science and technology are assigned to one of the different categories as follows:

	Oral	***Poster***	***Sum***
Applied colorimetry	14	49	63
Colour vision	13	39	52
Colour imaging	14	36	50
Multispectral colour science	21	20	41
Colour differences and appearance	14	21	36
Colour in computer vision	6	13	19
Colour physics	4	6	10
Colour vision with natural images	8	0	8
Camera and display characterisation	6	0	6
Computational colour constancy	5	0	5
Photoreceptors and colour vision mechanisms	4	0	4

Here, some topics of the Congress have been combined, such as “colour vision” includes “colour vision and ageing”, “colour imaging” combines “colour image capture, devices and media” with “gamut mapping, characterisation and display” and “evaluation of image quality”, “colour differences and appearance” combines “colour differences”, “colour appearance” and “colour appearance: ordinal, interval & ratio scales”.

A review of all of these papers cannot be given, however, some general lines of the oral papers will be highlighted and commented as far as the author is acquainted with special topics.

2. APPLIED COLORIMETRY

In colorimetry all discussion about measured values either tristimulus values or spectral reflectance factors starts with the question on their uncertainty. Since quality controls are demanded increasingly during the last years accreditation of colorimetric laboratories depends on quality statements including given numbers of uncertainty of measured values. To achieve such a statement calibration chains are needed form the laboratory to a reference institution that provides the most sophisticated instrumentation with a level of uncertainty much better than those in usual laboratory instruments.

Work from National Institutes was presented, that shows the newest generation of instruments. A reference tristimulus colorimeter was developed with a combined uncertainty level of 0,1% (k=1) and an uncertainty of chromaticity coordinates x and y at 0,0004 for illuminant A. This allows calibration of other tristimulus colorimeters. The increasing use of gonio-apparent paints in industry called for gonio-sensitive instruments, and indeed two new high accurate gonio-spectrometers were shown that allow for bi-directional measurement of spectral reflectance factors

with a great variability of angular combinations. Uncertainty statement was given for systematic effects at 0,2% and for random effects at 0,02%. Improvements of instrumentation was additionally shown for the construction of a sphere optimising an idea of Sharp and Little with a very good uniformity of the inner wall of 0,16%, and for the combination of a fast highly accurate goniophotometer with a tristimulus colorimeter to detect spatially very narrow “rainbow” colours in automotive headlamps. An idea of improving measured spectral reflectance factors is bandpath correction when the bandpass function is not triangular. An extended version of the Stearns and Stearns method was successfully tested for a LED spectrum.

A long standing discussion deals with the additivity rules of Grassmann as a basis for our vector interpretation of colour valence. A new experiment on proportionality and on transformability between sets of primaries was done using a large bipartite field (1964 colour matching functions) at low luminance levels (0,1-4,5 cd/m^2). The results showed deviations from predictions especially for a red colour, which only in part could be assigned to rod intrusion. Considering a similar experiment from the Colour Vision section for 1,8° bipartite fields showed, that the 1931 colour matching functions are good predictors in the main visual spectral range, however, with some deviations at the ends of the visible spectrum.

Scientific research of colour order systems became a little bit neglected in recent times. Is there nothing to do anymore? One paper shows that even in the long-known Munsell-System new effects of multidimensional scaling can be detected like the tilt of constant value planes at equal angle crossing the grey axis.

Illuminant metamerism is one of the most important effects in qualifying colorant productions. There was some debate about the best calculation of an index of metamerism. Here, an idea of Fairman was tested to be superior to older traditional versions. Standards on metamerism index should be rewritten.

Several papers dealt with colour rendering of light sources to show: an RGB-LED cluster is not good for illumination of museum art work, visual assessment of a colour rendering index favours the application of CIECAM02-colour appearance model (though not optimal), a design to simulate colour rendering for real objects was developed to allow predictions on the rendering effect of new light sources which is of great help for lamp producers.

For automotive finishes with gonio-apparent surfaces, CAD (Computer Aided Design) was introduced using new interactive graphics programs to transform gonio-spectral measures to monitor images and to allow visual change of rendition by change of viewing angle. Predictions for creation of new paints were satisfactory though no exact matches were attained.

Old definitions of contrast ratio turned out to be inaccurate and a revised Human Visual Contrast model using just noticeable difference steps to be better.

3. COLOUR VISION

Three papers dealt with visual problems of elderly persons with cataract or miosis. Corrective goggles and corrections of illumination could help them to see better.

Computer graphics were used to attain virtual reality of an image of a natural scene as natural as possible. This means to correct for non-natural adaptation during inspection of the image.

Is it possible to perceive a three-dimensional illusion of two-dimensional printed pictures? The answer is: yes, under certain circumstances, if scenes with strong perspective depth are viewed under a narrow angle and if some adjustments of the illumination in the show-room is performed.

New experiments with a wide range of observers provide astonishing uncertainty and variation of stimuli considered “unique hues”. This may be the reason, why only two hue-categories between adjacent unique hues are found (orange, violet/purple). What is the consequence for colour space scaling and colour difference evaluation?

Our colour memory of prototype objects such as skin, grass or sky is improved, if the presented colour to remember is not presented in isolation but is embedded in a natural picture. Our memory thus seems to act categorical and not cognitive.

4. COLOUR IMAGING

Colour calibration of displays is an essential to attain good rendering properties. The new generation of high dynamic range acquisition systems has a complex technical structure that makes colour calibration a sophisticated undertaking, however, a solution is possible adapting models for the calibration of other displays. CRT calibration may be done without measuring equipment, if you ask observers to set 4 primary colours and a neutral one for correct percepts. Uncertainties were in the range of those of the physical method. Similarly, an idea was presented of a psychophysical method of gamma correction of CRT displays without using a photometer.

Gamut mapping is a formidable task because it means to reproduce a picture from a display with a set of primaries on a printer with a quite different set of primaries. A model is developed that allows to correct for saturation in a picture in the direction of higher or lower saturation using a histogram adaptation technique. Another method was developed for newspaper printing called smooth gamut deformation algorithm. A test against three other methods showed a good improvement. Well, these procedures provoke questions about how accurate an original is reproduced. A solution might be to define local colour-differences in images. This was done using a new method of defining regions of interest in a picture, measuring colour-differences at selected points and asking observers about quality. First results showed a rather low tolerance level for local colour-differences.

Image compression is a way to save storage capacity. JPEG and JPEG2000 describe quality assessments, however, judgements of observers provide some insight how they might be improved using modern colour difference formulae. In images unavoidably noise is a source of image distortion. Reduction of noise may counteract colorimetric accuracy. A fast correction matrix algorithm provides a tool to find a compromise which allows for a balance between noise and colour accuracy.

5. MULTISPECTRAL COLOUR SCIENCE

Multispectral imaging is a rather new development of imaging that improves greatly colour communication and representation for electronic devices. However, data storage and handling became more complex and so did the formats used in different parts of the world. CIE Division 8 (TC-8-07) is working on a format that could become a standard to facilitate data handling.

Computer Aided Design in former years suffered from not displaying the effect of texture in the real world. To improve reproductions of texture on a display a Bi-directional Reflectance Distribution method for gonio-reflectances was introduced. Now, this method was combined with multispectral analysis to further improve colour rendering.

To reduce observer metamerism in DPL-projections the step from 3- to 6-primary projectors may be done. A laboratory version, though still costly, showed, how this aim could be attained using special filters. The same undertaking was started for a video-solution combining a six-band HDTV camera with a 6-primary display unit.

For certain applications the viewer of scenes wants to know about the type of illuminant, that illuminates them. A solution was proposed that compares second derivatives of the spectral radiance of a scene with spectral power distributions of known fluorescent illuminants.

For museums multispectral technical equipment for a number of tasks may be applied. In fine art paintings used pigments may be identified with help of multispectral camera systems with and without using prior knowledge of pigments under consideration. What is the best illuminant to produce a good showing of paintings for visitors? Multispectral analysis of paintings and a calculation of colorimetric values for illuminants of variable colour temperature astonishingly said: the greatest number of discernable colours was identified for an illuminant of 10 000 K, which is far from all the illuminants used nowadays in musuems. Museums of fine art, archives or libraries are highly interested to build image databases of paintings with adequate colorimetric accuracy. A matrix R method deduced from Wyszecki's idea, that any stimulus may be decomposed into a fundamental stimulus and a metameric black, was revitalised. A trichromatic camera combined with two absorption filters, calibrated with a colour checker, served for multipectral imaging. The resultant colorimetric accuracy tested for two colour checkers was very good at low indices of metamerism. Interestingly Wyszecki's method also served to construct spectral reflectances from RGB-measures using some assumptions about typical shapes of known reflectances. Digital archiving of three-dimensional museum objects may be done by measuring bi-directional spectral reflectances of objects and calculate a distribution function according to a model with a fast processing Wiener estimation technique.

The performance of spectral reconstructions by multi-channel spectral imaging greatly depends on the type of target used for calibration. Here, a calibration target of 70 samples from 9 pigments covering the widest possible gamut provided reconstructions of three colour charts with rather small colour differences.

In ink-jet printing metamerism may be reduced by using a spectral Neugebauer printer model with a new intelligent inversion of the Neugebauer equations.

To display pseudo-coloration of objects measured in the near-infrared a multispectral analytical system successfully is used, which allows to make more details visible than with the visible spectrum alone.

For modelling basis functions for finite-dimensional models of spectra a non-negative linear analysis provides physically interpretable solutions, which means filters may be designed accordingly.

6. COLOUR DIFFERENCES AND APPEARANCE

Colour-difference evaluation in most cases was developed for standard illuminant D65. When the new formulae were tested against data-sets for standard illuminant A all these formulae were not as good as for D65-illumination. Application of a colour adaptation transformation such as CAT02 improved the data, however, another choice could be to use a colour appearance model such as CIECAM02 .

Metallic and other effect paintings in the automobile industry provide serious complexity in colour-difference evaluation compared to uniform paintings. A special study tried to facilitate visual colour matching using colour pairs displayed on CRT-monitors related to measures at different bi-directional angles. The best conformity of measured results with visual judgements was found by special weightings of the set of used angles. An extension to texture in the samples revealed that discrepancies with colour-difference formulae exist for intercomparison of different texture in the sample pairs. An investigation of the suitability of simulating coarseness of metallic samples on a CRT was performed combining gonio-measurements, assessment of samples in a viewing cabinet and comparison with a simulation on CRT. Obviously CRT simulation of coarseness is quite well possible. A similar experiment aimed at identifying the parametric factors in CIE-colour-difference formulae for textured samples. Again CRT simulated sample pairs were constructed with varying degree of texture. And indeed the parametric factor for lightness had the strongest effect and increased

up to 2,1 for the most pronounced texture, however, the dependency of the factor on type of texture calls for more differentiating use in industry.

A colour-difference formula deduced from CIECAM02 was compared to CIELAB to investigate the effect of gamma of CRT displays on colour differences. Both formulae gave very similar results.

Look-up-tables for cross media transformation (e. g. from a scanner to a printer) should be built with large data size and more irregular positions of colour lattice points to receive good colour quality of the resulting print.

Visual sensitivity to contrast depends on colour and as well on spatio-temporal frequencies of a scene, and thus determines colour appearance. Experimental results may be used to improve colour quality of compression schemes.

Achromatic colour appearance is two-dimensional with lightness and "surface brightness" as the independent dimensions.

Changes of colour appearance due to change of illuminant was studied with a colour naming task. Dominating colour shifts were found for hue changes described as shift of Major/Minor Hue (MMH) border shifts. These may be used to assess colour appearance models.

A colour appearance model was developed for mesopic vision, which takes rod intrusion into account and which allows continuous change from scotopic to photopic levels of illumination.

7. COLOUR IN COMPUTER VISION

The performance of the compression of images using independent component analysis was tested in a computer experiment. Compression improves with patch size, however, noise may increase. A series of low-level mathematical filters may be used to compress the recent increasingly complex imaging techniques. Another way of image compression starts with JPEG2000 and adds non-linear gain control to improve compressed image content.

A mathematical procedure using combined colour and texture information allows for highly efficient separation of texture from colour in an image.

8. COLOUR PHYSICS

The Kubelka-Munk-Theory of light absorption and scattering in turbid media as widely known in colour recipe calculations for different types of colorants has some draw-backs because of simplicity. This may be improved, if the effect of light scattering considers the path lengths of light propagating through the medium. For the case of dye on paper promising results were given.

A new method to show rainbow holograms was presented.

An archaeological mica from the northwest of Argentina may have been used as interferential mirror by an ancient human tribe from which no other cultural remains were found.

A multidisciplinary co-operation to analyse the bronze type of a historic Chinese horse statue included several optical methods.

9. COLOUR VISION WITH NATURAL IMAGES

A digital camera with fast tuneable crystal filter served for hyperspectral imaging of natural scenes and assessment of the range of chromatic properties of the scenes. Judgements of colour constancy of computer simulated versions of the scenes indicated good constancy. An evaluation of luminance and chromatic changes under variable illumination showed chromatic attributes to be preserved at a large portion.

Why are the spectral sensitivity functions of our cones found at their actual spectral positions ? A shift of spectral sensitivity functions of L- and M-cones would provide more colour information, however, their actual position increases the ability to discriminate differences around 535-560 nm, and this could have been the essential profit during evolution.

The visual system effectively estimates the spatial and chromatic distribution of illumination in scenes in estimating surface colour even when illumination is a mixture of punctuate and diffuse sources.

Have we overlooked the three-dimensional space around us when talking about colour appearance? Experiments say: yes, we use 3D information to identify colour appearance independent of the adaptation of the eyes.

Perceived brightness and perceived contrast may be used in identifying 3D objects across illumination conditions.

10. CAMERA AND DISPLAY CHARACTERISATION

LEDs may serve for a new generation of displays. In this case the characteristic functions must be known to find the transformation of device dependent colour space to device independent XYZ. These functions are different to those of CRT- or LCD-displays, however, may be handled as well. The same knowledge is needed for the new generation of Plasma Display Panels. Can a digital still camera replace a tele-spectroradiometer in characterising the colorimetric quality of a LCD display ? The answer is: yes, if the camera is sufficiently calibrated and a certain tolerance is accepted. A 3CCD camera can be calibrated to measure small colour-differences as tested for near grey samples at a reliable accuracy. To identify tristimulus values of stained glass from the medieval a calibration procedure for a digital camera was developed. A method is given to use a digital camera in a way that the colorimetric hue plane is preserved.

11. COMPUTATIONAL COLOUR CONSTANCY

Good colour constancy may be attained, if a statistical based method, which uses statistical knowledge about lights and surfaces in a scene, and a physics-based method, which looks for the way how physical processes manifest themselves in images, are bound together. Horizontal motion enhances colour constancy of moved objects. This has implications for co-processing of colour and motion in cortical pathways. To reconstruct the original colour appearance of a scene statistics of illuminants and surface reflections may be handled in a way starting from known real statistics of reflectances and illuminants, combining with statistics of the retinal image. To solve the problem of colour constancy a method of introducing a chromagenic filtering technique for RGB-imaging was used. The method has to search for the best filters to avoid the problem of outliers.

12. PHOTORECEPTORS AND COLOUR VISION MECHANISMS

This topic cannot be highlighted adequately as the contents of two invited papers, which cover the central contributions, were not known to the author. However, the connection of physiological colour description and colorimetry is the basis for better understanding the origin of our everyday handling of colorimetry such as colour-difference evaluation and colour appearance. Are there any possibilities of tracing back our model variables and their derivatives to physiological modelling?

13. FINAL REMARK

The Congress AIC2005 was a very vivid, very diverse showing of different scientific and technological lines in colour science. Some lines become predominant like multimedia technique including multispectral imaging. But also the problems of colour-difference evaluation and appearance seem not to be solved in a sufficient manner. Some topics were more or less under-represented such as the problems of fluorescent colours and especially the interconnection of colour physiology and colorimetry. There is much to do for the future!