Softproofing System for Accurate Colour Matching and Study of Observer Metamerism

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Abstract

A new design of a softproofing system for accurate colour matching is presented in the first part of this paper. In a cabinet, an LCD display is mounted in the viewing plane and illuminated by fluorescent tubes. This arrangement allows for the direct visual comparison of original surface colours with their displayed reproductions face to face. Test colours are placed in cutouts of a mask on top of the screen for colour matching experiments (colour checker mask) or for calibration purposes. The device provides a means for very sensitive proofing of the reproduction algorithm and offers the study of the variability between different observers. The reproduction algorithm applied is based on the spectral specification of all the essential components of the system and allows for fast switching between colour matching functions of different observers considered. Experimental results and studies on the reproduction for different observers and observer metamerism problems are presented in the second part of the paper. Colour matching experiments for a white colour under different illuminants have been performed for a number of different persons. The results show very well reproducible shifts of the experimentally matched colours in the chromaticity diagram, if compared with the original colours for the CIE 1931 standard observer. The results differ for the left and right eye matches for most of the observers. Any person exhibits a typical direction of the shifts like a personal characteristic or a "finger print", yet, the directions of shifts in the chromaticity diagram are different for different observers and any direction might appear. All the shifts of all persons form a cloud around the original colour in the chromaticity diagram.

Introduction

The task of a softproofing workstation is the reproduction of colour images on a display at such a quality that the colour appearance of reproduced colours cant be discriminated from those of the originals. Originals might be a natural scene, a printed image or a well defined data set of a colour image. A common workstation to proof this reproduction consists of a display on one hand and a separated lighting booth placed aside the display on the other hand. In the lighting booth, an original image is viewed under a light source with a well defined illuminant and, on the basis of digitised data of this original, the image is reproduced for the same illuminant on the display. If the system is calibrated and adjusted well, the observer expects to perceive the same colours from the display and from the original in the lighting booth.

However, in practical systems, this goal is quite difficult to achieve for a number of reasons. First of all, digitisation and colour capture of the original is not perfect if colours are captured by an RGB camera system with only three colour channels. Perfect colour reproduction can only be expected if the colours of the original are described by their spectral stimuli [1-3]. Thus, only reproductions of spectral images should be considered. A second problem is based upon the fact, that the display is located in a surrounding with a backlight different from the one of the original image presented in the lighting booth. Hence, different colour appearances of colours in the lighting booth and colours on the display have to be taken into account [4,10]. Moreover, the spectral power distributions of technical light sources (fluorescent tubes in most cases) are not uniform. They exhibit a number of strong spikes resulting in spectral stimuli of the original colours which are quite different from those generated by typical LCD-displays. Observer metamerism problems are to be expected for this reason. A recent and very detailed study of observer metamerism has been published in [5] with the conclusion, that observer metamerism in softproofing systems is not that dominant except for white or grey colours. Other publications are quoting larger effects [6,7]. In addition, the effect of strong spikes on colour vision is not clear and there might be more complex adaptation processes in the retina as was recently discussed in [8]. Further studies clarifying all these problems are desired.

A main disadvantage of the commonly used softproofing with a display on one hand and its spatially separated lighting booth on the other hand is the distance between both devices. The observer has to keep colours in his mind for comparison while moving his eyes or head from the display to the lighting booth and vice versa. This makes colour comparison more difficult and introduces uncertainty in colour discrimination. In the first part of this paper, a different softproofing architecture is described to overcome this problem. This architecture is a further development of an earlier proposal published in [9], where an area for viewing originals and a display for image reproduction were arranged in one plane. The display is now installed again with its surface mounted in a viewing plane, yet, under a common light source which illuminates both the display and the original. The luminance of light reflected from surface colours arranged in the viewing plane and the luminance of respective colour reproductions by the display are adjusted by computer control. Moreover, for the testing of colour matches and for calibration purposes, a so-called colour checker mask has been introduced by which original colours and their reproductions can visually be compared on the screen of the display face to face and thus, viewed within the same surrounding. In this case, neither colour appearance problems nor adaptation due to the surrounding light scenario play a role and highest sensitivity is guaranteed for direct colour comparison. Only the absolute amount of eventual colour differences might be influenced by surrounding conditions [10].

Moreover, the colour checker mask can be used at any time to visually check the instantaneous reproduction stability of the system and as well, to check the reproduction quality of softproofing systems operated at any location.

If he system is equipped with the colour checker mask, it provides a means for accurate experimental colour matching experiments and for studying various effects like observer metamerism. The ability to study those effects is the main goal of the project described in this paper. Following this goal, the second part of the paper deals with experimental results on matching experiments using different observers. The colour management of the reproduction allows for fast switching between different models of observers for that. Reproductions based on different observers result in noticeable changes of colour matches. Pertinent colour differences are evaluated.

Finally, the results of a larger colour matching experiment with a number of human observers are discussed. The observers had to match a white colour reproduced for the standard observer by manual control and under different illuminants. Matches have been measured separately for the left and right eye.

Design of the softproofing system and method of colour comparison

The basic construction of the softproofing system is sketched in Fig. 1. An LCD display is mounted in a lighting cabinet with its screen being part of the plane of viewing. The plane of viewing is illuminated by fluorescent tubes aligned in the head of the booth and oriented at an angle of approximately 45° to the surface and the horizontal centre of the display.

Direct visual comparison between original colour patches and colours reproduced by the display is realised by a colour checker mask positioned in front of the plane of viewing. The mask provides a number of cutouts and one half of each cutout is covered from behind by a sheet of a surface colour with black backing, whereas the other half is held open to enable a displayed colour behind the mask to become visible.

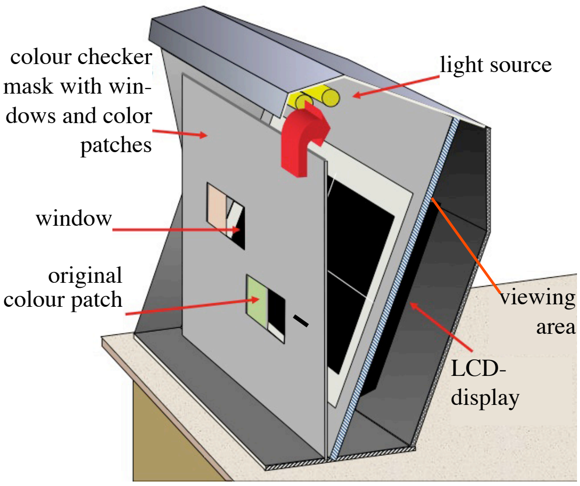

Figure 1. Basic principle of the softproofing station with lighting booth, plane of viewing and LCD-display, linear fluorescent bulbs and colour checker mask in front.

The experimental laboratory model of a softproofing station with a mask providing printed colours according to the Macbeth ColourChecker is shown in Fig. 2. If colour reproduction is adjusted well, there will be no - or nearly no - visible colour difference between each half of any window of the colour checker mask. This allows an easy and accurate visible check of the quality of the system.

In the laboratory model, there are two types of fluorescent lamps installed in a rotatable drum, one set for the illuminant with correlated colour temperature of 6500K (marked "D65" in the following) and another one for 5000K (marked "D50" respectively). By rotating the drum electronically, each one of the sets can be brought into its well defined position to illuminate the viewing plane correctly. The length of the light tubes is 120 cm. Hence, there is additional space to position colour images also aside the display for the purpose of colour comparison.

Figure 2. Laboratory model of a softproofing station equipped with 24" LCD-Display and a mask in front, providing the colours of a color checker. A second colour checker mask is shown in front.

The illumination under approximately 45° causes irregularities of the irradiance of light within the area of viewing. Colour patches in the upper part of the area will look much brighter than those placed in the lower part. This uniformity problem is reduced by a number of mechanical apertures positioned in front of the light tubes. These light controlling apertures contain holes or shapes of a special design in order to smoothly block part of the light directed towards the upper part and the centre of the viewing area. A typical mask looks like a saw-tooth causing a smooth change of light-blocking from top to bottom. The apertures have been calculated and optimised by a computer light path analysis. The final uniformity within the area of the display of the laboratory model was measured to be in the range of +/- 6 % of the reflected brightness in the centre. A typical distribution of the final brightness in vertical direction is shown in Fig. 3. In commercial lighting booths, transparent light scattering components are often used to solve the uniformity problem. The reason why this is not applied here is the ambition to achieve the original spectral distribution of the light sources not being disturbed by any transparent scattering process in the path of the light.

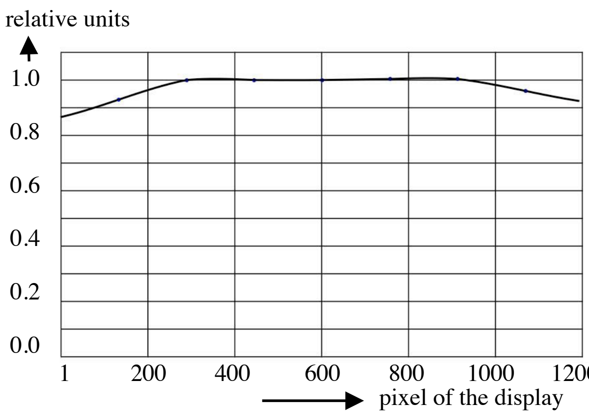

Figure 3. Relative brightness measured by using a white reference patch (barium sulphate). This was placed and moved on the screen of the display and illuminated by the fluorescent lamps of the softproofing station. The light reflected by the reference patch was picked up perpendicularly to its surface and the results are plotted for the vertical direction in the middle of the LCD-display in this figure.

The viewing plane aside the display is covered by a material of neutral grey showing the reflectance of approximately 20 %. Moreover, the whole viewing area is surrounded by a frame of a white surface colour. This "white reference colour-frame" was found to stabilise colour adaptation if different images of large area and of different average colours are to be displayed.

The system can also be operated in an illuminated office environment, if the office illumination is stable, no natural light through windows from the outside and no gloss on the surface of the display are present. In this case, the additional illumination from the office is measured locally and spectrally near the viewing plane and incorporated in the reproduction algorithm.

Calibration of the softproofing system

The aim of the system is to reproduce a colour such as to match its original colour (e.g., a surface colour patch) if the original colour would be placed at the same location on the screen. Accordingly, the calibration of the softproofing system requires two essential steps: in a first step, the local distribution of the brightness of the display has to be matched with the brightness of light, that is reflected from the surface of colour patches arranged on the screen and irradiated by the light source. Secondly, the display itself has to be calibrated, to ensure correct reproduction of tristimulus values corresponding to those of original colours.

To compensate for the remaining irregularities of the irradiance of the light source across the screen (approx.. +/- 6%, see figure 3 e.g.), a white reference colour checker mask with a regular raster of cutouts covering the whole display area is used. These cutouts are all equipped with white patches of the same colour. In a first approach the tristimulus values of this colour are reproduced behind the cutouts of the mask at the same brightness level for all the cutouts. In a second procedure, the brightness level for each cutout of the mask is successively visually matched by changing its corresponding control value step by step. If the brightness of a reproduced and an original colour in a cutout match, the corresponding brightness level is stored. The final result is a raster of brightness levels for the matched reproduction values. From this raster, a raster of correction values is generated, which is afterwards interpolated and stored for each pixel of the screen in the form of a correction table. This "brightness correction table" is applied to the reproduction process of any colour image later on.

As proposed in [12], the evaluation of the brightness correction table might also be performed automatically in the future and in addition, pixel oriented complete three dimensional colour correction might be applied.

Detailed work has been published on the calibration of displays for accurate colour reproduction [13-14]. In this earlier work, a display is the main component determining the essential parameters and the white reference point for reproduction. In the process of calibration of the new design as proposed in this paper, a white point of the display as a reference does not play any role. A white reference for the adaptation of the eye in the device discussed here is defined by the white frame around the viewing area, which is illuminated by the respective fluorescent lamps. This in turn defines a grey axis to be used within a gamut mapping algorithm. Moreover, the display is set to provide a large gamut in a custom mode with an average colour temperature for a full, native level control of the RGB signals.

As mentioned already above, the softproofing system should be flexible enough to allow for the reproduction for any model of an observer and to be able to switch between observers fast. Commercial colour management systems typically require large LUT`s and have not been applied here for this reason. A special realtime algorithm has rather been developed to transform given tristimulus values into RGB signals at the input of the display (Fig. 4). This mathematical algorithm requires a number of parameters describing the physical properties of the display. These parameters are calculated from a set of 340 emission spectra measured at 1 nm steps and generated for selected RGB-signals. Together with the colour matching functions of the observer just selected, the necessary parameters for the transformation model are calculated. This calculation of display profiling parameters is performed once for each switch to a new observer.

The transformation of tristimulus values into RGB-signals at the input of the display comprises a gamut mapping algorithms also working in real time. This algorithm considers the maximum range of RGB-signals as the limit and works in realtime.

The scheme of calculating tristimulus values for the colours to be displayed is sketched in Fig. 5. On the left hand, the evaluation of the tristimulus values of the colour of a pixel (e.g.

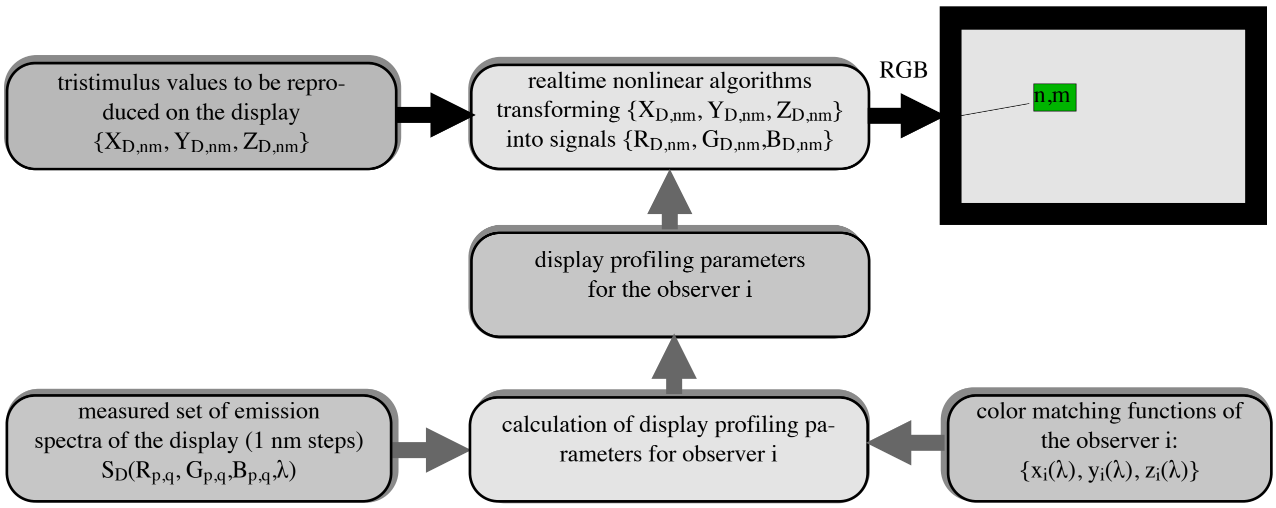

Figure 4. *Diagram of the control of the display for colour reproduction at a pixel {n,m} by a realtime non-linear mathematical algorithm and, scheme of precalculation of profiling parameters from a measured set of emission spectra of the display for combinations {p,q} of RGB signals. Profiling parameters are calculated for any optional colour matching function of an observer. Emission spectra are measured at the distance of 60 cm from the screen.*

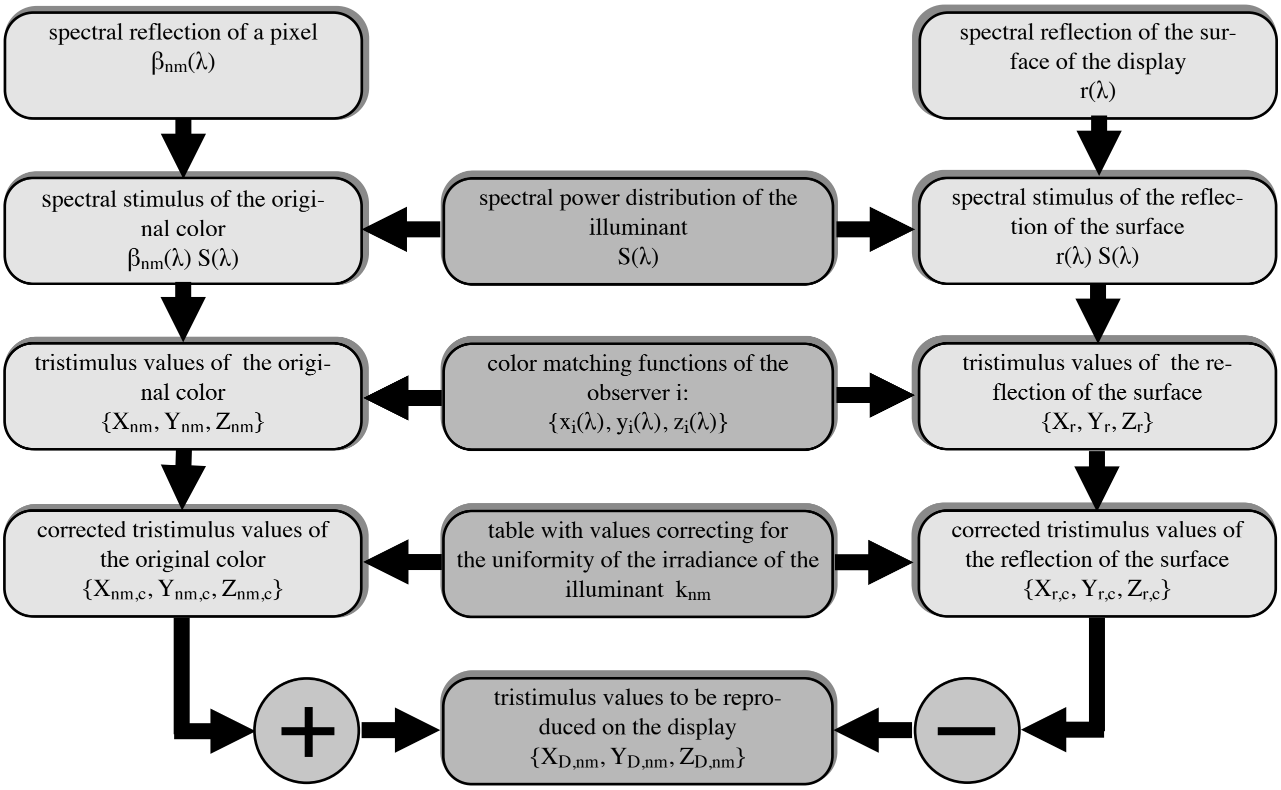

Figure 5. *Scheme of the reproduction of an original colour described by its spectral reflection function $\beta_{nm}(\lambda)$ and the spectral irradiance S{λ} at pixel {n,m} and scheme of consideration of light reflected from the surface of the display (reflectance r(λ)). Before tristimulus values are reproduced, they are corrected by values of the uniformity correction table to match the brightness of the display with the brightness of the illumination within the display area.*

those of a spectral image) is outlined. The tristimulus values are calculated for the colour matching functions of a selected observer and finally, they are multiplied by correction values to match their brightness with the local distribution of the light. Since a part of the light of the illuminant is also reflected from the surface of the display, tristimulus values for surface reflection are calculated as well (right hand side of Fig. 5). In professional display devices, the surface reflection is below 0.4 % and hence, the contrast for displayed images is 240:1, though the display is illuminated. Finally, the calculated tristimulus values for reflection $\{X_{r,c}, Y_{r,c}, Z_{r,c}\}$ are subtracted from the tristimulus values of each pixel $\{X_{nm,c}, Y_{nm,c}, Z_{nm,c}\}$ and the result is reproduced on the display, having in mind that the subtracted part is physically added again during visual observation. The colour matching functions {x(λ), y(λ), z(λ)} in Fig. 5 might be replaced by {l(λ), m(λ), s(λ)} or any other matching functions of observers if desired.

Experimental quality of the calibration of the display

The quality of the calibration of the display has been tested by using a number of 512 randomly distributed combinations of RGB signals and by measuring the respective emission spectra. From these, the tristimulus values have been calculated for the CIE 1931 standard observer. The colour errors between the measured and calculated tristimulus values using the real-time profiling model are plotted in Fig. 6. Most of the errors are due to noise of the measuring equipment and quantisation noise. The mathematical errors by the analytical model are smaller. In the last block of the diagram (numbers 449 to 512),

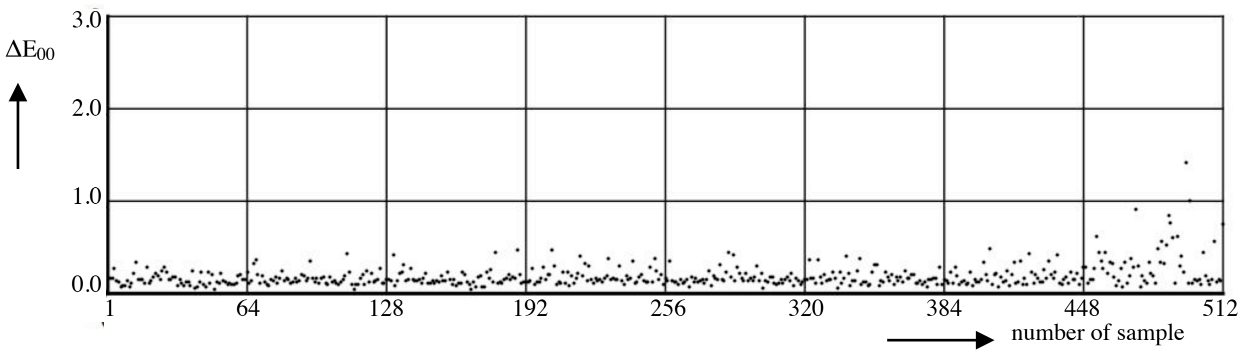

Figure 6. *Colour differences between colours reproduced by the display and colours calculated from the profiling parameters (Fig. 4) for a set of statistically distributed RGB-signals at the input of the display (Eizo CG241W, CIE 1931 standard observer). Values near the grey axis and very low values are concentrated in the last section. The reproduced colours on the display are calculated from their measured spectral distributions (1nm steps) for the CIE 1931 standard observer.*

RGB-signals centred around the grey axis have been concentrated. Errors of ΔE00 > 0.5 within this block are those of very dark lightness with Y < 0.5%;

Colour reproduction and metamerism

The reproduction algorithm and the calibration of the system is based on very accurate measurements of all the relevant spectral distributions of the reflectance of original colours, the power distribution of light sources and the irradiance of displayed colours. These measurements have been performed within the wavelength range of 380 to 720 nm at 1 nm steps (optial bandwidth 1.2 nm). Hence, every reproduced colour is expected to match its original colour patch within the cutouts of a colour checker mask accurately. In fact, experimental results on reproduced colours show, that this is fulfilled quite well for saturated colours, yet, for colours near the grey axis or for a white colour, slight colour shifts are often observed. The nature of these shifts was found to be quite different for different observers. Some observers perceived a more reddish, others a more bluish or greenish shift. The slight mismatches between reproduced and original colours would rarely be visible, if the colours were placed at a large distance. Yet, due to the direct positioning side by side, even small mismatches are registered.

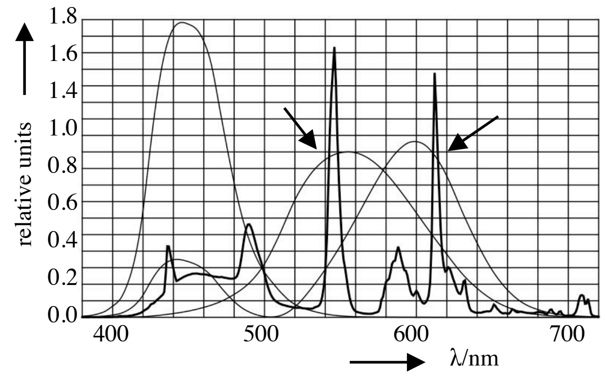

Figure 7. Spectral emission of the display for a white colour reproduction and colour matching functions of the CIE 1931 standard observer. The arrows point to critical parts where high accuracy of colour matching values is required to get correct valuation of spikes.

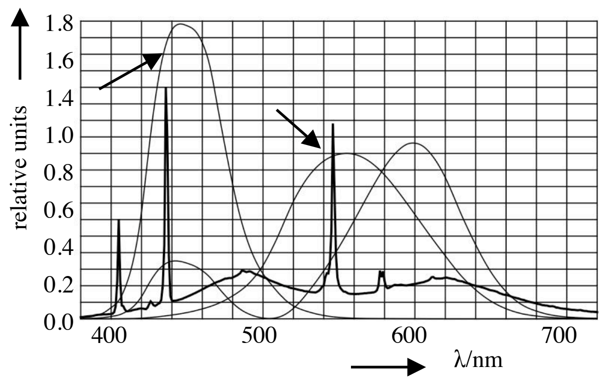

Figure 8. Spectral stimulus of a white colour under a fluorescent lamp "D50" and colour matching functions of the CIE 1931 standard observer. The arrows point to critical parts where high accuracy of colour matching values is required to get correct valuation of the influence of spikes.

The only difference between the original and its corresponding reproduced colour can be found in the spectral distributions of their stimuli. In Fig. 7 and 8, the two spectral stimuli of a white colour ("efi - gravure semimatt" in this case) are plotted together with the spectral matching curves of the CIE 1931 standard observer. It is obvious, that a number of strong spikes at different critical positions for both colours will contribute essentially to the integrated products forming the tristimulus values. Very sensitive elements within the evaluation of tristimulus values are the values of colour matching functions at the location of spikes.

The different spectral stimuli of an original and its reproduced colour point to observer metamerism as the reason for the different mismatches by human observers. A number of different colour matching functions well known from the literature has therefore been used to study the influence of observer metamerism as a limiting factor.

Experimental conditions

Since the matching of a white colour is most sensitive, studies and results of experiments on the matching of a white colour are discussed in the following. The area of colour patches used in experiments was 2x2 cm^2 according to the size of a colour patch seen by the 2°-observer at the distance of 60 cm. Each observer was asked to keep the distance of 60 cm and to look perpendicularly onto the screen of the LCD-display, since noticeable changes of the reproduced colour appeared otherwise. Any experiment was performed after a warm-up time of the system of at least 5 hr.

The effect of different colour matching functions

The reproduction of a white colour has been calculated and measured for a number of colour matching functions as listed below:

1. CIE 1931 2°-standard observer
2. CIE 1964 supplementary 10°-observer
3. Judd 1951 2°-observer [11]
4. Vos modified 1978 2°-observer [11]
5. Stiles Mean Colour Match 1955 2°-observer [11]
6. variable observer according to publication CIE 170-1 for 2°-and the age of 30 [12]
7. variable observer according to publication CIE 170-1 for 2°-and the age of 65 [12].

Before starting to present results expressed e.g. in terms of ΔE00, a few words should be spent on the problem, how to validate colour differences of non-standard observers. In general, it is a matter of definition how to define colour differences between observers based on different metrics of colour matching functions. In this paper, the problem is solved by using only colour differences measured via the CIE 1931 standard observer, for whom colour difference formulas are defined. This is realised by the following consideration. One and the same observer will always perceive the same colour, if the RGB-signals at the input of the display are the same. For the reproduction of a deviating observer, the resulting RGB-signals will differ from those of the reproduction for the CIE1931 standard observer and both observers will be described by different tristimulus values. If the tristimulus values for the standard observer are changed afterwards in such a manner, that the RGB-signals at the input of the display match those of the reproduction for the deviating observer, a colour difference can be defined for the standard observer from the respective change of tristimulus values. In this case, the difference to the deviating observer is validated as it is perceived by the standard observer. This scheme has been applied here to derive the colour differences between observers as shown in Figures 9 and 10. Changing the tristimulus values for the standard observer can be performed either manually with visual control or automatically by the mathematical reproduction algorithm.

In Fig. 9, the chromaticity points for the white colour reproduction assuming 7 different observers are plotted in the chromaticity diagram. Each observer produces its own RGB-signals at the input of the display. The chromaticity values "as seen" by the CIE 1931 standard observer are evaluated in such a manner that they match the RGB signals of the respective deviating observer as explained already above. Point 1 stands for the CIE 1931 standard observer. The other points for the observers 2 - 7 show noticeable differences to each other and to point 1.

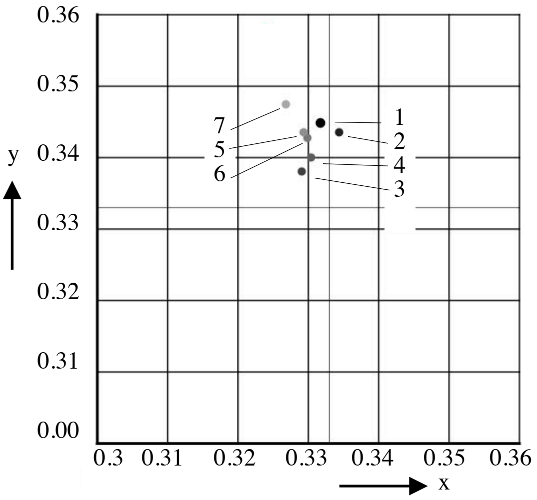

Figure 9. *Chromaticity coordinates of a white colour ("efi - gravure semimatt") as seen by the CIE 1931 standard observer (1) and under the illuminant "D50", measured and calculated from the reproductions of different deviating observers with different colour matching functions (2-7).*

In Fig. 10, the corresponding colour differences expressed in values of ΔE00 are given. The results show, that there are quite large differences between reproductions for the observer 1 and the others. This fact is also visually confirmed.

The results of Fig. 10 do not show the absolute mismatch to the original colour for each observer. This would have to be evaluated separately. Another question is, if the colour matching functions provide a realistic picture of observers in this system. In a more detailed experiment with human observers, more insight into the problem was evaluated therefore and results are presented in the following.

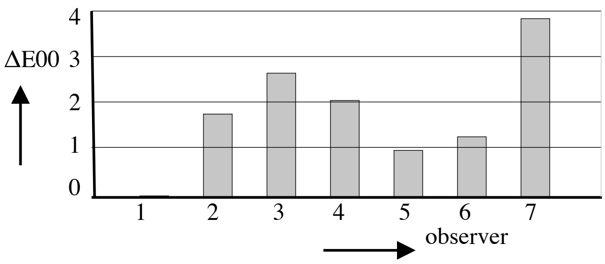

Figure 10. *Colour differences of reproductions between different observers 2- 7 and the CIE 1931 standard observer 1, "as seen" by the standard observer.*

Metamerism by human observers

For the measurement of the matching of colours by human observers, a colour checker mask with grey surface and with only one cutout on the centre was used. In the left half of the cutout, a white colour patch, the original colour, was fixed (Phoenix Imperial APCO II/II in this case) and the other half was held open to view the reproduced colour of the LCD display aside. The reproduction was always started with a reproduction calculated for the tristimulus values of the CIE 1931 standard observer. After that, the test person had to manually change the (X-Y), (Y-Z) and lightness values via computer control until a complete match with the original colour was achieved. This experiment was performed under the illumination by fluorescent lamps "D50" as well as "D65". Since both lamps need a large warm-up time, the experiments for the different illuminations were carried out on different days.

Very early, when starting the experiments, it turned out that some of the test persons exhibited considerable differences between their left and right eyes. Some test persons were not able to find a satisfactory match when using both eyes at once. Sometimes, one eye was dominant, sometimes not. Obviously, the brain does not take the average colour perception. All the experiments were therefore performed separately for matches with the left and right eyes.

In Fig. 11, the result of the matching experiments of 9 typical test persons is shown in the chromaticity diagram. Two clouds of matches are presented for the two illuminants "D50" and "D65". The big points in the centre of the clouds show the positions of the original colours under the respective illuminants. The points around the chromaticity values of the original colours are the matching results for the left and right eyes of the test persons.

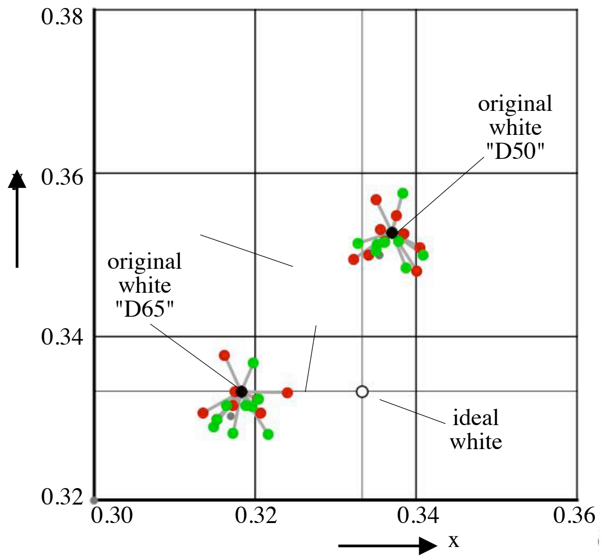

Figure 11. *Matching results of 9 test persons shown in a cutout of the chromaticity diagram. Indicated are the chromaticity points of the original white colour for two different illuminants and the chormaticity points of matching with the left (red points) and right (green points) eyes, respectively.*

At first glance, the cloud of points around the chromaticity values of the original colours looks very much like the result of statistical variations or uncertainty of measurements or uncertainty of colour perception of the test persons. Yet, this is not true, as will become clear from the detailed view below.

Fig. 12 presents the matching results of test person 1. Matching the original colour requires this person to shift the chromaticity values into the direction of green. The matching points of the left and right eye are remarkably different. Comparing the results for the two different illuminants, the nature of colour shifts is quite the same in both cases, although the two experiments have been performed on different days. It should also be pointed out that the experiments with this test person have been repeated many times with time lags of several days or weeks. Nevertheless, the results are reproducible and stable with the uncertainty of the order of only +/0.0005 for the chromaticity coordinates.

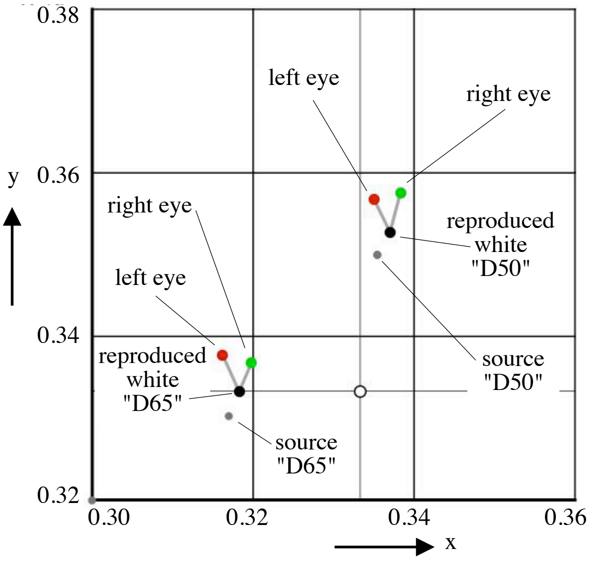

Figure 12. *Matching results of test person 1 (male, European, 71 years old) in the chromaticity diagram. Indicated are the chromaticity points of the original white colour for two different illuminants and calculated for the CIE1931 standard observer and the chormaticity point of matching results for the left and right eyes.*

The respective results for test person 5 are given in Fig. 13 and for test person 6 in Fig. 14. The matches of these test persons point into very different directions, yet, for one person the directions are again quite the same for the two illuminants, though they have been measured in independent experiments.

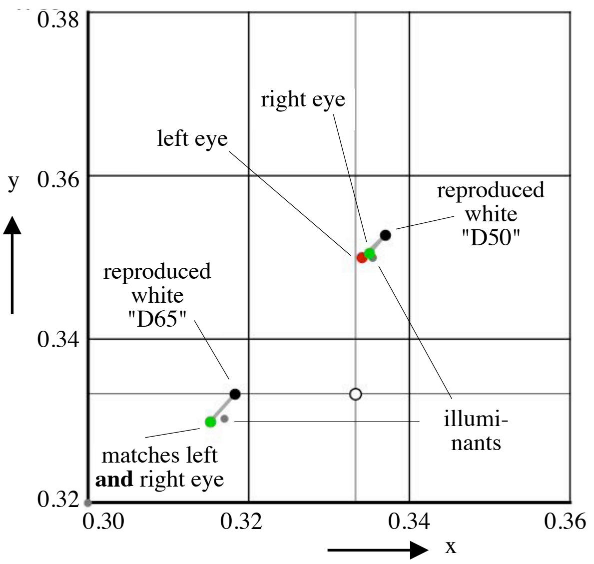

Figure 13. *Matching results in the chromaticity diagram for test person 7 (male, European, age 27). Indicated are the chromaticity points of the original white colour (CIE1931 standard observer) for two different illuminants and the chormaticity points of matches with the left and right eyes.*

The shifts of matching points compared to the original colour points in the chromaticity diagrams, their directions and magnitudes look like characteristic "white colour finger prints" of the colour viewing capability of each observer.

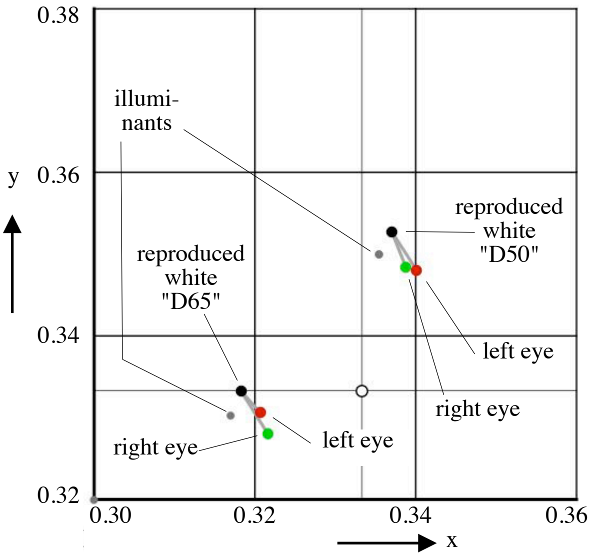

Figure 14. *Matching results in the chromaticity diagram for test person 5 (female, Asian, 23 years old). Indicated are the chromaticity points of the original white colour (CIE 1931 standard observer) for two different illuminants and the chromaticity points of matches with the left and right eyes.*

Table 1 summarises the colour differences resulting from the matching experiments. The test persons have "normal" colour vision capabilities. The colour differences are defined by the differences between the experimental matching points and the respective original tristimulus values calculated for the standard observer. Most of the differences are in the range of ΔE00 = 3 - 4 and lower. Two of the testpersons (3 and 8) perceive colours quite similar as the standard observer. Only one person reaches ΔE00 = 5.2. The order of magnitude of these variations is in good agreement with the order of magnitude of variations found for the case that a number of different published colour matching functions was applied (see Fig. 10).

In conclusion, the results of the matching experiments show, that observer metamerism is the main limitation to the colour reproduction quality of the system. Each human observer perceives its own characteristic mismatch if colours are reproduced for the standard observer. The mismatch can be visualised in the form of a characteristic "white colour finger print" in the chromaticity diagram after the matching experiment. Only a small part of measured mismatches was found to be due to uncertainty of perception or quantisation.

Table 1: Colour differences for matches of a white colour

	person	age	colour difference in DE00	
			"D50" left-/ right eye	"D65" left_ / right eye
1	male, european	71	3.85 / 2.95	4.40 / 1.97
2	male, european	30	1,24 / 1.41	2.18 / 2.25
3	female, european	25	0.57 / 0.73	1.00 / 0.91
4	male, european	35	2.21 / 2.29	2.22 / 2.03
5	female, asian	23	5.21 / 4.21	3.60 / 5.95
6	male, european	31	1.22 / 0.94	4.62 / 3.31
7	male, european	27	1.51 / 1.41	1.56 / 1.56
8	male european	36	1.33 / 0.00	0.19 / 1.73
9	male, european	41	3.64 / 4.43	4.38 / 2.27

Summary and Outlook

A new design of a softproofing workstation has been presented. This realises the possibility to compare an original colour directly with its corresponding reproduced colour displayed on the screen adjacent to the original. Moreover, a colour checker mask has been proposed allowing for a single or a set of test colours to be compared on the screen of the display with their reproductions. The essential advantage is, that each pair of colours is viewed within the same surrounding, by this way getting rid of problems of colour appearance or adaptation due to different background or surrounding lighting conditions. The processing pipeline uses images of colours generated from spectral image data or spectral colour patch measurements. Due to careful spectral measurement and measurement of all the relevant parameters of the illumination and display of the system, the quality of colour reproduction is very high.

Moreover, if the softproofing station is equipped with a colour checker mask and its corresponding electronic data set of colours, the colour reproduction quality of the station can be checked visually at any time or any location at high sensitivity. This solves an essential problem of colour communication: the reproduction quality of colours can checked anywhere. Otherwise, recalibration is necessary.

Colour comparison face to face is the most sensitive method for colour difference perception and besides its capability for checking colour communication systems, the proposed equipment provides a means for sensitive colour matching experiments. In addition, fast switching between different observers for any reproduction has been realised. On this basis, a number of experiments could be started to study the reproduction for different observers and the results show, that noticeable differences between colours for different observers appear. None of them provided a perfect match for the available human observers up to now and this kind of observer metamerism limits the final reproduction quality. Another matching experiment with a white colour and a number of test persons has shown that a cloud of matches for the different persons around the reproduction for the standard observer is obtained, if the matches are plotted in the chromaticity diagram. It turns out, that this is not only the result of uncertainty of measurement or colour perception, but to the larger part the result of characteristic mismatches of the observers due to observer metamerism. Mismatches up to $\Delta E00 = 5$ are observed, but there is also a number of persons matching the standard observer quite well. The matches for every test person were very well reproducible even after days or weeks. Each observer exhibited his own characteristic direction of a chroma shift towards reddish, blueish or any other hue. No general direction of colour shifts for all the observers was noticed, any direction appeared.

The results on observer metamerism have been studied at a white colour so far. Though a white colour is most sensitive in this respect, experiments on different colours have to performed in the future to complete the results. Since observer metamerism is the essential limitation to the colour reproduction quality, ideas should be developed how to overcome this problem in the future. On one hand, observer metamerism would be reduced if light sources and emission spectra of LCD-displays became broader with less spikes and, on the other hand, there is perhaps the possibility to find optimised colour matching functions for each individual observer to optimise colour reproduction at least for one user.

Another possibility to reduce observer metamerism will be the use of multichannel displays [3].

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