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Usability of Calibrating Monitor for Soft Proof According to CIE CAM02 Colour Appearance Model

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Abstract:

Colour appearance models describe viewing conditions and enable simulating appearance of colours under different illuminants and illumination levels according to human perception. Since it is possible to predict how colour would look like when different illuminants are used, colour appearance models are incorporated in some monitor profiling software. Owing to these software, tone reproduction curve can be defined by taking into consideration viewing condition in which display is observed. In this work assessment of CIE CAM02 colour appearance model usage at calibrating LCD monitor for soft proof was tested in order to determine which tone reproduction curve enables better reproduction of colour. Luminance level was kept constant, whereas tone reproduction curves determined by gamma values and by parameters of CIE CAM02 model were varied. Testing was conducted in case where physical print reference is observed under illuminant which has colour temperature according to ISO standard for soft-proofing (D50) and also for illuminants D65.

Based on the results of calibrations assessment, subjective and objective assessment of created profiles, as well as on the perceptual test carried out on human observers, differences in image display were defined and conclusions of the adequacy of CAM02 usage at monitor calibration for each of the viewing conditions reached.

Key words:

Soft-proof, CIECAM02 Colour Appearance Model, Monitor Calibration

1. Introduction

Digital proof is defined as a practical element of process control and since in the last few years the demand to reduce time and costs in proof production has moved into the focus of interest, the use of monitor for proof generation acquired considerable importance. So as to ensure adequate reproduction of print colour, accurate monitor calibration and characterization are crucial. During the calibration basic properties of light (correlated colour temperature and luminance level) under which physical print will be evaluated needs to be taken into account, because colour appearance heavily depends on these parameters.

According to the ISO 12646:2008 (Displays for colour proofing - Characteristics and viewing conditions), the white point of the monitor (which is to be used for soft-proof) should be calibrated at correlated colour temperature of D50 (5000° K) and the luminance level should be set to 80-120 cd/m2[1]. Beside the white point chromacity and the luminance level, electro-optical response of a device has to be defined. The electro-optical transfer function describes the relationship between the signal driving a given channel and luminance produced by that channel and is also known as tone characterization *(Kwak & MacDonald, 2000)*. It is usually defined as a combination of gamma, offset and gain *(ISO 12646:2008)*, where in the LCD technology due to the panel construction, gamma is the only important parameter. The nonlinearity between the digital signal and the luminance level is based on power law, and gamma is the numerical value which describes this nonlinearity. For LCD displays relation is given as follows *(Borbély, 2008)*:

$$Y = X^{\gamma} \quad (1)$$

where Y stands for luminance of the display, X for normalized input signal and γ for gamma value.

[1] These values are reference values for CRT monitors. Since there is no additional standard for LCD technology and since it enables achieving higher luminance levels, values from 100-120 cd/m2 are recommended for LCDs.

The fundamental transfer function of LC material has an S-shape characteristic *(Leckner, 2004)*, but usually many manufacturers choose to mimic *(Marcu et al., 2002)* the digital drive circuitry for a general purpose CRT, producing the transfer function that obeys a power law variation *(Leckner, 2004)*. Since 1996 and the creation of SRGB, standard gamma value of 2.2 is widely used as a standard for monitor calibration both for CRT and LCD monitors. It enables a better reproduction in very dark and very light areas, and produces the smoothest display of gradients for the most monitors used *(Fraser et al, 2005)*.

With the development of colour appearance models it became possible to perform monitor calibration in such a way that the tone reproduction curve is optimized to the luminance of the ambient light in order to achieve the most effective contrast ratio (the combination of monitor and ambient light). CIECAM02 model is used and curves are defined for each of the 3 basic viewing conditions (dark, dim, average). Dim condition in CIECAM02 is defined in cases where surround relative luminance is in a range of 0-20% of the luminance of the scene i.e. image white *(Fairchild, 2005)*. Stated by Fairchild (2005): "In practical application the surround can be considered to be the entire room, or the environment in which the image (or other stimuli) is viewed", so dim conditions are often used to describe the level of ambient light for viewing images on display.

Soft proof method relies on the interaction of monitor and printer profile in such a way that all colours in document are first converted to printer profile and then mapped to colours of monitor. Since every CMYK colour space has smaller gamut then RGBs, some of the gamut mapping algorithms have to be involved in order to achieve a better reproduction. Perceptual and Saturation Rendering change sourcing colours in a significant manner so should better be avoided when defining the rendering intent for soft proof. Colorimetric rendering, on the other hand, can be used both for mapping colours from input to output profile, and for output to monitor profile conversion *(Figure 1)*. The first part of calculations is generally not of special importance and it is recommended that Relative Colorimetric with Black Point Compensation (BPC) should be used for transformations from input to output profile *(Homann, 2007)*. The other part of calculations (printer to monitor colour space) is very important since it defines the final appearance of a reproduced colour. It is also important to use Colorimetric rendering in this phase and choosing the right one depends on whether the simulation of a printed medium needs to be performed or not. If the goal is to simulate paper colour, Absolute Colorimetric should be used, if not, Relative Colorimetric is proven to be a better choice *(Homann, 2007)*.

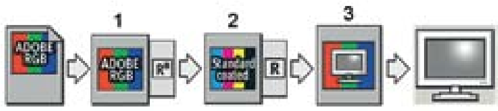

Figure 1. Recommended rendering intents for colour conversion in soft proofing. (1 - profile of an input device, 2 - printer profile, 3 - monitor profile, R - Relative Colorimetric rendering intent, RB - Relative Colorimetric rendering intent with Black Point Compensation)

Beside adequate monitor calibration and profiles interaction, viewing condition and technique has to be defined. Technical Committee (TC) 1-27 (established by CIE for Specification of Colour Appearance for Reflective Media and Self-Luminous Display Comparison) defines certain guidelines for performing soft-proof comparison. These guidelines are basically defined for the testing of colour appearance models, but they can also be applied for practical assessment. Three viewing techniques for colour- appearance matching are defined by TC 1-27: haploscopic, binocular and magnitude estimation technique. The first two techniques are recommended for paired- comparison psychophysical experiments and are often used in several manners.

Binocular viewing techniques are those in which both the original and the reproduction are viewed with both eyes, while with the haploscopic technique each eye views a different stimulus *(Braun et al, 1996)*. There are three binocular techniques marked as memory, successive and simultaneous. As summarized by Braun et. al (1996): “In memory viewing, observers adapted to an initial set of conditions for at least 1 min, viewed the original under these conditions, adapted to a second set of conditions, and viewed reproductions under these conditions. Observers then made judgments on the reproductions with- out viewing the original again. Successive-binocular viewing is similar to memory viewing except that observers are permitted to look back at the original, if necessary. They readapted to each set of viewing conditions before proceeding.”

Both of these techniques require some memorization of the original, which is not the case with the simultaneous technique which involves side-by-side comparison of the original and the reproduction. With haploscopic viewing, successive and simultaneous technique can also be performed. The biggest drawback of these techniques is that the cognitive mechanism of discounting the illuminant may not occur, and the advantage is that no memorization is needed and hence fewer mistakes can be made during the assessment. *Table 1.* summarizes the major attributes of various viewing techniques where the word Natural indicates that the technique is a natural or common way to view images, Quick - that the psychophysical experiment is reasonably quick, Adapted - that observers fully adapt to both conditions and No memorization - that the memorization of the original is not required *(Braun et al, 1996)*.

Table 1. Advantages of various viewing techniques.

Viewing technique	Natural	Quick	Adapted	No memorization
Memory	+		+	
Successive binocular	+		+	
Simultaneous binocular	+	+		+
Simultaneous haploscopic		+	?	+
Successive haploscopic		+	?	+

2. Methods and Materials

The monitor Samsung SyncMaster T220 was used to display image for a soft-proof LCD. Since this monitor has a TN panel, and due to its other characteristics, it does not belong to the professional class of devices. Prior to the calibration it was tested in order to define whether this model was appropriate for soft proofing. Tests were conducted according to the ISO 12646:2008, where the tested parameters were resolution, gamut, display size and visual uniformity, geometric accuracy, white point chromaticity and luminance level. Tests show that this monitor was appropriate for soft-proof and therefore it was used in further testing.

Only software calibration could be carried out with this monitor, so all important parameters were set via the basICColor display 4.1.9 software. Spectroradiometer EyeOne Pro was used to measure display response. Chromacity colour with correlated colour temperature of 5000° K (standard illuminant D50) was defined as white point according to ISO 12646:2008. Luminance level for white was set as highest and for black as lowest possible, and two sets of calibration were conducted with these parameters. All occurring differences related to the TRC, where curve defined by gamma value of 2.2 was used in the first, and the perceptually uniformed curve defined by CIECAM02 model in the second set.

Besides calibrating for D50, which is in accordance with the standard for soft-proof, two sets of calibration with exactly the same parameters and standard illuminant D65 were made. This was due to the fact that this illuminant is still widely used in graphic industry and that many designers and web developers prefer D65 to D50 as the monitor white point. Profiles were defined as Look-Up table based (16 bits) in order to achieve the highest possible precision.

After calibration assessments of achieved values with different TRC were made using BasICColor display software (option: Validation) with Eye-One spectroradiometer. Parameters assessed were: tone reproduction curves for each colour, contrast ratio, luminance level for black and white, and also colour difference for 24 specific colours (measured values were compared to reference values from the ICC profile). List of colours used for calculating ΔE_{76} is given in *Table 2*., where all colours are defined by their digital RGB values.

Table 2. Colours used for calculating colour difference for calibration assessment

No.	R	G	B
1	255	255	255
2	224	224	224
3	192	192	192
4	160	160	160
5	128	128	128
6	96	96	96
7	64	64	64
8	32	32	32
9	0	0	0
10	128	0	0
11	255	0	0
12	255	128	128
13	0	128	0
14	0	255	0
15	128	255	128
16	0	0	128
17	0	0	255
18	128	128	255
19	0	128	128
20	0	255	255
21	128	0	128
22	255	0	255
23	128	128	0
24	255	255	0

Beside the assessment of basic parameters achieved by means of calibrations, profiles generated with different TRC were compared too. The aim was to define whether differences between profiles are big enough to justify different approach during calibration. Profiles were compared by their gamuts and by average colour difference of 24 colour patches of Digital Colour Checker test chart. Gamut volumes are measured in PatchTool software (option: Gamut Tools) and differences in Chromix ColorThink Pro software (option: Color Worksheet) by using Lab values from Color Checker reference file and calculating output values through transformations defined by each profile. Differences were expressed for profiles generated for same colour temperature, where colour difference formula from 1976 was used (ΔE_{76}).

Calibration assessment gives information about achieved parameters and can be very useful when defining which TRC enables better contrast and tone reproduction. Profile comparison gives information about differences in cases when profiles generated with different TRC were used, so it can be well used to define whether differences would be visible to human observer or not. None of these tests give any insight in usability of profiles for soft-proofing i.e., which calibration enables better tone reproduction and closer matching with actual print.

In order to define this, a perceptual test which includes 20 observers was carried out, during which observers were asked to estimate the degree of matching between print and monitor preview. Image used for evaluation was generated in a way to include all elements of importance for reproduction such as: gradients, extremely saturated colours, pastel colours, memory colours (colours of sky and grass), skin tones, primary and secondary colours of additive and subtractive mixing and their combination. All chosen elements on test image had few details, so that observers could focus on colour and not on the image itself.

When testing colour perception it is important that pictures which are to be evaluated are surrounded by a white frame of at least 1 inch in order to distinguish the image from the background. Outside the white frame it is necessary to have a grey frame of approximately the same width which simulates the background and facilitates observer's adaptation when changing viewing conditions *(Fairchild et Reniff, 1995)*. It is recommended *(Braun et al, 2006)* that grey colour be Munsell N8 or 18% gray from Kodak Q60 test chart (in Lab colour space this corresponds to 16, 0, 0). On the rest of the viewing field (display area or area in viewing cabinet) pure black should be defined in order to simulate the absence of chromacity in surround of stimulus (image).

Since all these requests have to be fulfilled, the frame around test image is expanded for about 2,5 cm and filled with white. All-around white frame, grey frame with Lab values of 16, 0, 0 was positioned and the rest of the image area was filled with pure black (Lab 0, 0, 0). Dimensions of test image were 28x43 cm because it had to be displayed on 22" screen. On the printed test image the black frame was slightly wider in order to fill the area of light box. *Figure 2*. represents the test image, with all important elements marked.

Figure 2. Test image used for evaluation of color matching. Elements of importance marked as:
a-gradients, b-saturated colours, c-pastel colours, d-skin tones, e-memory colours, f-colours of additive and subtractive mixing, g-white frame, h-gray frame, i-black frame.

For the purpose of printing, the test image is converted to CMYK in Photoshop CS4 application through Convert to profile option. A profile monitor generated according to ISO 12646:2008 was used as a source, while we choose Coated Fogra39 (recommended by ISO for printing on coated papers - ISO 12647-2:2004) as destination space. Transformation was done with Relative Colorimetric rendering intent and Black Point Compensation (BPC). For purpose of printing coated Mitsubishi semi-glossy proofing paper was used (spectral characteristics defined by Lab values of 94.1, -0.9, -2.0) and printing was performed on EPSON StylusPro 9880 which was certified as proofing device. As a printer profile ISOcoated_v2_eci.icc was used and for transformation from document to printer profile Absolute rendering. Printing was driven from EFI XF server on resolution of 720 dpi by using all 8 inks.

After printing, printed sheet was placed in colour viewing booth Agile Radiant Lightbox 5. With this cabinet simulating standard illuminants D50, D65, A, TL84 (4100 K, very close to F11) and UV light is possible. Before carrying out perceptual test, viewing cabinet was also tested in order to define how close it really can simulate standard illuminants D50 and D65 used in further studding. Tests were conducted according to ISO 3664:2009 in Babel Color CT&A software with spectroradiometer Eye-One with diffuser added during measuring. Luminance level, CRI (Colour rendering index), MI (Metameric Index) and chromacity tolerance was measured. For both D50 and D65 luminance level was very high - for D50 it was 1342 lux, and for D65 it was 1178 lux as shown in *Table 3*. CRI and MI were satisfactory *(Table 3)* and also chromacity tolerance of the white point. Tolerance is expressed as the distance of ideal position of white colour under specific illuminant specified at the plane of viewing, according to the 1976 u'10, v'10 UCS system.

Table 3. Parameters achieved by testing the colour viewing cabinet

Standard illuminant	Luminance level (lux)	Metamerism index	Colour rendering index	Chromacity tolerance
D50	1342	C	95	0,005
D65	1178	C	96	0,005

CS4 was used to display test image on screen options of Photoshop and for quick change of the default monitor profile we used Display Profile software. For each profile generated for certain colour temperature untagged test chart was shown in Photoshop where as working space Monitor profile was used. This ensures that certain monitor profile was source space for further conversions. Picture was converted in Coated Fogra39 with Relative Colorimetric and BPC since the same conversions were used for printing. For simulating colours of a printer option Proof Setup was used (View meny) where ISOcoated_v2_eci.icc profile was used as a device to simulate together with Absolute Colorimetric. Reverse transformation (from device colour space to monitor space) which is on-fly operation is in Proof Setup menu defined by Display Options. Paper colour option assumes Absolute Colorimetric, Simulate Black Ink Relative without BPC, and if none of the options is chosen, Relative Colorimetric with BPC is default rendering intent during conversion. Since the simulation of paper colour is performed by calibrating the device, and differences between monitor colour space and both CMYK profiles are significant *(Figure 2)*, Relative Colorimetric with BPC was used i.e. none of the options in Display Options dialog box was chosen. That way some losses in tonal values are expected, but relation between tones are preserved, which is much more important when viewing images. After conversion and the choice of the simulation method, test image was shown on full screen, so that nothing else was on the display at the moment of evaluating.

Twenty observers between 21 and 32 years of age were chosen for the perceptual test – 10 of them being female and 10 male. They were all experts in the field of imaging science and graphic industry in general. Before the very evaluation all observers were tested by classic Isihara test and also by Farworth Munsell 100 test (by Color Vision software) in order to estimate their ability to distinguish colours with similar psychophysical characteristics. The test has shown that all observers have normal vision and that they are certainly able to notice changes in presented colours.

Successive binocular technique was used for viewing, although simultaneous binocular was described as a more natural and easier method for evaluating colours during soft-proofing *(Braun et al., 2006)*. This was due to the fact that with successive technique complete adaptation on viewing conditions is ensured, which certainly leads to much accurate results.

Printed original and image on screen with this technique are to be placed at 90 from each other with respect to observers. While observers inspect the printed image which is placed vertically in the viewing cabinet, the monitor should be black. Similarly, the cabinet should be covered while an observer looks at the display. This ensured that observers could not see both images at the same time and reduced stray light. In this technique period for adaptation and inspecting image is also specified – the observer should first look at the grey card illuminated in light booth for about 60 s (time needed that 90% of chromatic adaptation of viewing field take place *(Fairchild & Reniff, 1995)*), study printed original under certain illuminant for as long as they want, turn towards monitor and first adapt on monitor grey for a minute then evaluate image which is to be shown on the display. Observers could never see both, printed image and reproduction at the same time, but they can observe the original image back and forth any time. The setup of the scene for successive binocular technique is shown on *Figure 3*.

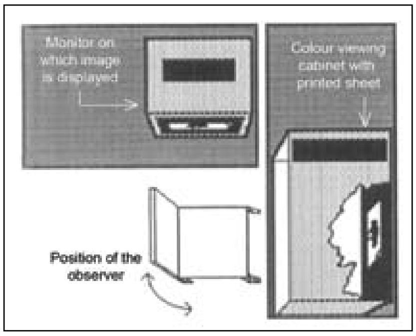

Figure 3. Top view of setup used for successive binocular viewing techniques

Both, a printed and a displayed image were positioned at 90° from each other, while the observer was at a distance of ca. 0,5 m from each image. Printed image (referred as original) was placed vertically and at approximately the same height so that both images could be on the same viewing level. For the purpose of adaptation, grey image (Lab 16,0,0) was printed with exactly the same parameters as test image and also one grey picture of the same colour values was generated for displaying on screen. Written instructions about evaluation were given to all observers as the first part of questionnaire and all additional pieces of information were given verbally. Room in which evaluation is performed was kept in total dark, with no other light to affect judgments. Light for which colours were to be tested would be turned on in the viewing cabinet and observers were asked to focus on grey image for a minute. The printed test image was then shown to them and they were asked to look at any element they want to for as long as they need. During that time a black image was presented on the monitor. After that, light in the viewing cabinet was turned off and the observers were asked to focus on grey image on the screen for a minute and then to evaluate the test image (whole or just one element). The test image would show first with profile generated for specific colour temperature with gamma curve and then with CAM02 curve in a manner explained before. Observer can easily switch between two images by using Display Profile software. After the evaluation the observer could look back at the cabinet (light in the cabinet would be turned on, black image would be shown on the monitor) if needed and give their opinion about matching the degree for each image presented. First profiles generated for D50 were evaluated and then exactly the same procedure was carried out for D65.

Observers would rate the degree of matching with grades from 1-5 where meanings of the grades are explained as:

1. completely non-matching
2. low degree of matching
3. partially matching
4. high degree of matching
5. completely matching in perceived colours.

Since the test image consisted of 6 elements, the observers were asked to evaluate each element and to rate it partially. They were given enough time for each step, and after the evaluation they had to write the grades in the questionnaire. Elements were marked in the same manner as in *Figure 1* and the same was shown on the graphic in the questionnaire in order to make it easier for the observers. After grading each element of the test image, observers should also choose and note which image in their opinion is a better reproduction of printed image – the one shown when the source profile is generated with standard gamma curve, or the one with CAM02 curve. The results of calibration and profile assessment and perceptual test together with the discussion are given as follows.

3. Results and discussion

Measured values of the parameters chosen for calibration assessment are given in *Table 4.* and 5. for colour temperature D50 and D65 respectively.

Table 4. Values measured after calibrations performed for colour temperature of D50

Values measured after calibration	Calibration performed with standard gamma TRC	Calibration performed with CAM02 TRC
White point luminance	203 cd/m2	203 cd/m2
Black point luminance	0.17 cd/m2	0.33 cd/m2
Achieved contrast ratio	1218:1	634:1
ΔE_{76} max	6.12	4.82
ΔE_{76} average	1.87	1.29

For colour temperature D50 better results are achieved when calibration is performed with TRC defined by gamma value of 2.2. The luminance of black point has a lower and the contrast ratio almost double value then the ones achieved with CAM02 tonal reproduction curve. However, colour differences (both maximal and average) are lower in the case of the second calibration type. This means that the gamma curve will ensure the use of maximum monitor colour range, but when it comes to the accuracy of reproduction, the second TRC type will give a better result.

Table 5. Values measured after calibrations performed for colour temperature of D65

Values measured after calibration	Calibration performed with standard gamma TRC	Calibration performed with CAM02 TRC
White point luminance	217 cd/m2	217 cd/m2
Black point luminance	0.19 cd/m2	0.33 cd/m2
Achieved contrast ratio	1121:1	660:1
ΔE_{76} max	14.16	5.81
ΔE_{76} average	1.91	1.74

The calibration performed for D65 displayed the same issue as that for D50. Maximum colour difference for the first calibration set is much higher in this case, and average ΔE_{76} for both calibration types can be categorized as clear difference. For this colour temperature reproduction curves for each colour has pretty much the same shape, while in case of D50 red curve is positioned little lower in highlights for calibration performed with CAM02 parameters *(Figures 4. and 5.)*.

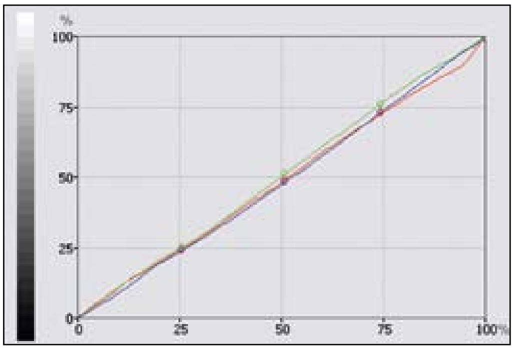

Figure 4. Tone reproduction curves for calibration performed for D50 with gamma 2.2 curve

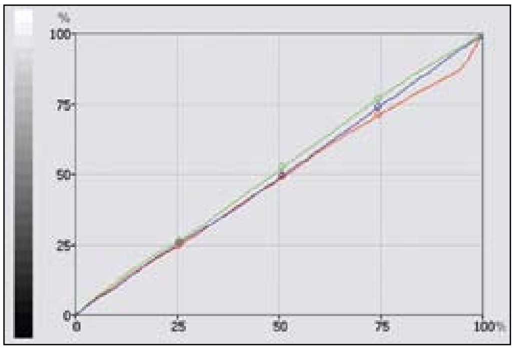

Figure 5. Tone reproduction curves for calibration performed for D50 with CAM02 curve

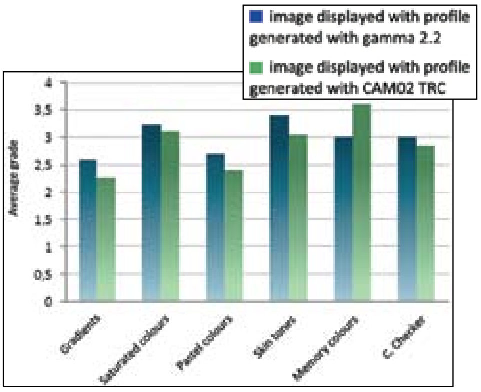

Figure 6. Average grades for each element of test image given for profiles generated for D50

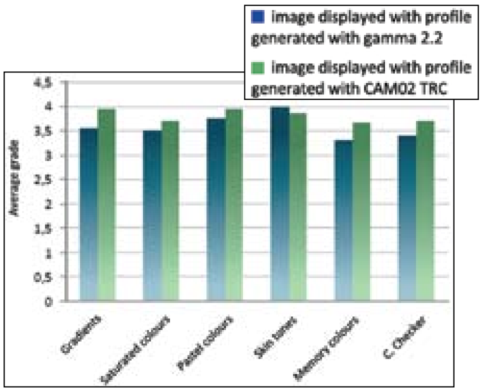

Figure 7. Average grades for each element of test image given for profiles generated for D65

During profile assessment gamut volumes and colour differences between differently created profiles are observed. It is shown *(Table 6.)* that more colours can be displayed with profiles created with CAM02 parameters (according to gamut volumes) and also that colour difference between profiles are very clear which means that the difference in image reproduction will be more then noticeable to human observer.

Table 6. Results of profiles assessment

Profile created for colour temperature of:	*Gamut volume for profiles created with gamma curve*	*Gamut volume for profiles created with camo2 parameters*	*Colour difference between profiles (ΔE76)*
D50	752 058	762 950	3.25
D65	737 445	759 857	2.29

Perceptual test gives an insight of colours which are better reproduced by different calibration types. *Figure 6.* shows average grade of every test image element given by all observers for profiles generated for colour temperature D50, while *Figure 7.* represents the results for colour temperatures D65.

From *Figure 6.* it can be seen that the profile generated with gamma 2.2 curves gives a better reproduction for almost all elements of the test image. A sole exception is the memory colour, which is not surprising since perceiving these colours triggers one of the basic mechanisms of human perception and it is therefore logical that for those colours a better reproduction is achieved with the CAM02 based profile. *Figure 7* shows the opposite case, where for almost all elements (an exception are skin tones) a higher degree of visual matching is achieved with the CAM02 based profile.

Figures 8. and 9. display the percentage of observers who choose one or the other profile as a better choice for soft proof. Different profile types are marked with colours.

As Figures 8. and 9. show in case where profiles are generated for D50, a better simulation is achieved with gamma profiles, while in case of D65 80% observers chose CAM02 profile.

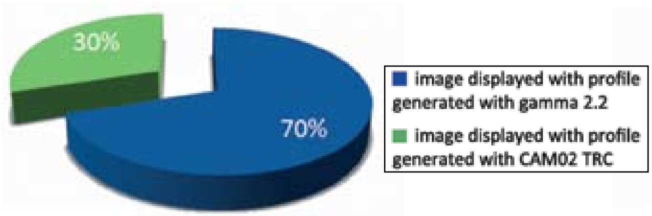

Figure 8. Percentage of observers who choose a certain profile as better for soft proof for the D50 colour temperature

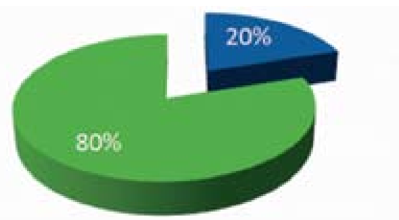

Figure 9. Percentage of observers who choose a certain profile as better for soft proof for the D65 colour temperature

4. Conclusion

Soft proof is a highly specific method for colour assessment since there is an attempt to simulate the reflection of light by means of a device that works on emission principle. Also, the simulation itself is not easy to perform since the response of every device has to be described very precisely and the interaction between device profiles needs to be adequate.

Based on results of calibration and profile assessment it can be concluded that better colour reproduction (according to colour difference values and gamut volumes) can be achieved by calibrating monitor with taking into account viewing conditions. Using the standard, 2.2 gamma curve in these cases enables a better contrast ratio. Since there is no colour without the observer, the focus of this work was set on perceptual test and observers opinions. It is shown that for almost every colour used when colour temperature D50 is the goal, better matching between printed and displayed image is achieved with settings recommended by ISO standard. Exceptions are memory colours where CAM02 profile enables better reproduction. When calibration is performed for colour temperature of D65, better visual matching is ensured with CAM02 profiles.

Colour appearance models became very important in graphic industry ever since better reproduction and simulation of perceived colours can be achieved by incorporating them into colour management workflows. Nevertheless, this paper demonstrates that it is not always appropriate to use the CAMs. Tests performed on other LCD monitor models show pretty much the same results. For colour temperature defined by the ISO standard, standard settings (for TRC) give better results, and for memory colour and D65 colour temperature calibration where CAM02 setting was used enables better visual matching.

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