Analysis of color profile quality of digital projector

Iva Molek[1], Dejana Javoršek[2]

[1] The Secondary School of Multimedia and Graphic Technology Ljubljana, Pokopališka 33, 1000 Ljubljana, Slovenia, e-mail: iva.molek@smgs.si

[2] University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Chair of Information and Graphic Arts Technology, Snežniška ul. 5, 1000 Ljubljana, Slovenia, e-mail: dejana.javorsek@ntf-uni-lj.si

Abstract: The aim of the present study was to analyze the display of colors in digital projection. For this purpose the digital projector NEC NP210 was used. The measurements were performed in accordance with the instructions and recommendations of ISO standards. Our goal was to research the creation of color profile of the projector using a EyeOne Pro spectrophotometer and to establish whether the size of color gamut of standardized sRGB color space can be reached by characterization of the digital projector modules. By using the color chart Color Checker Classic, the photometric and colorimetric accuracy of the characterized and uncharacterized projection were evaluated. In the final part of the research, comparison between the colorimetric accuracy of the computer screen and the digital projector was performed.

The results showed that by module characterization of the NEC NP210 Movie projector in studio conditions, the same size of the color space could not be achieved as by using the default sRGB module. Evaluation of colorimetric accuracy by using the digitalized color chart Color Checker Classic provides usable results, especially when the display of chromatic colors with emphasis on skin tones, and achromatic colors with emphasis on grey balance or chromaticity respectively, were examined. Based on the obtained results of the computer screen and digital projector comparison, it could be concluded that both compared computer screens match the standards. Overall, the NEC NP210 projector with the sRGB default module without profile could be also used if necessary. Thus, we can sum up that digital projection displaying standardized sRGB color space could not be comparable to a high quality CRT or LCD computer screen.

Key words: digital projector, color space, color display, characterization.

1 Introduction

Although digital projection has been an established method of presentation for some time now and continues to gain on popularity, the field of accurate color display is relatively unexplored. Experience has shown that colors are displayed inaccurately or imprecisely, yet the sources that would determine how precisely, in fact, they are displayed, cannot be found even in established institutions, such as UGRA. Inaccurate color display is particularly critical in education, where colors are mentioned in some way or other, in advertising, in presentation of designed printed material, TV or Internet advertisements, and in the presentation of works of art (paintings). Accurate color display in digital projection is, according to the currently known sources, more art than science, and is based on experience, hypotheses, and speculation.

Projectors have had a very long history and over the last few years, they have become a component part of every serious presentation. Nowadays digital projectors are used to project static and dynamic contents, and function with the help of a wide array of various projection technologies and modules respectively. With the aid of the digital projection modules we can choose from different pre-set options; some projectors can be geometrically calibrated (manual setting of contrast, brightness, correlated color temperature) and characterized. An image from the computer, VCR, DVD player or any other source that has compatible connection to the projector can be projected to a computer screen or a projection screen, white wall or any other type of white surface. When a source of light (computer or video) is connected to the digital projector, the electronic circuit inside the projector processes the signal in order to display the image (M. S. Brennesholtz et al., 2008). Display assembly is based on various technologies. We use digital projectors based on Liquid Crystal Display technology - LCD, that function on a similar principle as LCD computer screens, projectors based on Digital Light Processing technology (DLP), and projectors based on Liquid Crystal on Silicon technology that combine LCD and DLP technologies.

While monitor calibrating, characterization and certification are scientifically well processed (ISO 12646:2010, 2010; ISO 3664:2009, 2009; S. Kunihiko, 2007; S. Kunihiko, 2008), digital projection is poorly explored. Certified monitor, capable of depicting AdobeRGB color space or even ECI-RGB, reproduces colors accurate to $\Delta E^*ab < 1.5$ (ECI, 2014). To what extent it is possible to reach such power by using digital projector is not mentioned in the sources. Mainly, they focus on the description of characterization and the issues related (Ugra; K. Cooper, 2014), and even here it is still not evident how the digital projector was set and in what conditions it operated. Even though it seems logical, it is discussed (Ugra) whether in order to reach irreproachable color presentation the projector should be characterized each time when the nature of light in the room or the type of the screen changes. Projectors are characterized in dark (low light) spaces to create color profiles for various correlated color temperatures of the white point (usually 5000 K, 6500 K and natural white in given circumstances), whereas in realistic circumstances of the presentation the most appropriate color profile is chosen only approximately. It is pointed out by the same source that the distance between the optical sensor, the projector and the screen, play no particular part, other sources specify these relations (Ugra).

Various researches apply to the geometrical calibration of digital projectors (S. Matt, 2003; S. Park et al., 2010), experience (Ugra; K. Cooper, 2014), and while some sources (K. Cooper, 2014) claim that by calibrating and characterizing the digital projector in one's subjective judgment it is possible to improve visual depiction of colors, others (M. Ashdown et al., 2014) list excellent results that are regarded valid for six basic colors only.

Our goal was to perform objective colorimetric evaluation of digital projection based on the depiction of natural colors in different observation conditions. For that purpose, on the basis of the ISO 11315-1:2003 (ISO 11315-1:2003, 2003), ISO 11315-2:2011 (ISO 11315-2:2011, 2011) and ISO 12646:2010 (ISO 12646:2010 , 2010) standards the digital projector was examined from different points of view. The effects of two projection distances, different projection modules, measuring wedges and charts, applications for creating color profiles, methods for evaluating of displayed colors were determined. For digital projection Microsoft Power Point was used, while in order to create suitable color charts Adobe Photoshop CS4 was used. Color charts were created by the recommendations of ISO and sRGB standards.

As the majority of digital photographs are taken in standardized sRGB color space, the aim of the research was also to establish, among other things, how well the digital projector NEC NP210 displays it in the given circumstances.

2 Experimental

In our research various types of equipment such as: projection equipment (digital projector, projection screen), characterization software, and other necessary equipment (studio lighting, plumb line, level, tape measure, air conditioning appliance and thermometer, etc.) that enabled performance under controlled and repeatable conditions, were used. The projector was a low priced NEC NP210 digital projector, used in classrooms (About projectors, 2014), based on the DLP technology (Digital Light Processing). Graphics display resolution of the projector was XGA (1024 × 768 pixels) and had six projection modules: High Bright, Video, Movie, Graphic, and sRGB.

For photometric and colorimetric evaluation of the projected colors, the EyeOne Pro (i1Pro) (X-Rite) spectrophotometer was used. Combined with suitable programs support it is basically used to measure reflected and emitted light when it comes to regular photometric or colorimetric evaluation. Spectrophotometer also supports various color management applications and it is appropriate not only for calibration and characterization of computer screen, scanners, digital cameras and printers, but also for establishing light conditions in the room and digital projector characterization. Luminance measurement (Lv) is supported efficiently by the KeyWizard, yet we faced a serious problem regarding the unknown field of vision of the instrument and sighting a specific point of the screen. After much trial and error, we solved the problem with the improvised use of the visor taken from a geodetic level, whereas in measuring color charts in the centre of the screen we used the projection of a suitable sighting target. Calibration and characterization of the digital projector were performed using established applications; applications i1Match 3.6 and basic combined with i1Pro spectrophotometer, application basICColor display 4.1.22 combined with i1Pro spectrophotometer. Figure 1 shows the scene settings for calibration and characterization. Digital projection was performed and evaluated in accordance with the standards ISO 11315-1:2003, ISO 11315-2:2011, and ISO 12646:2010. Colorimetric accuracy of the digital projection was evaluated using Color Checker Classic color chart.

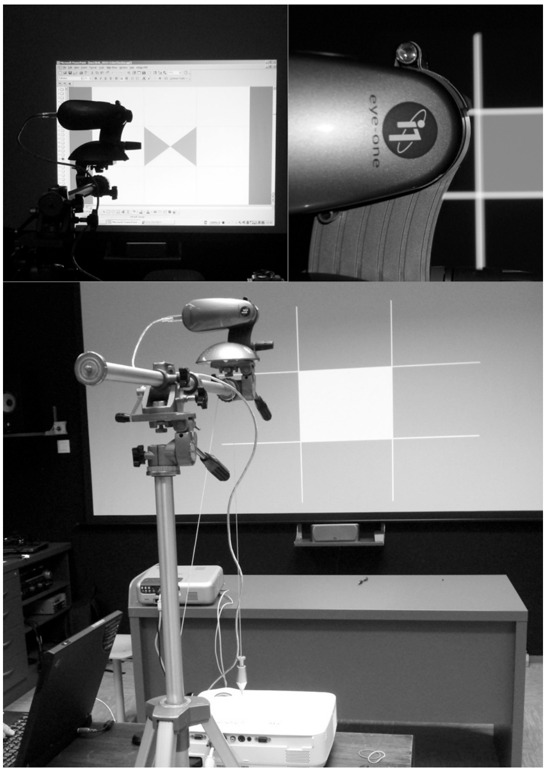
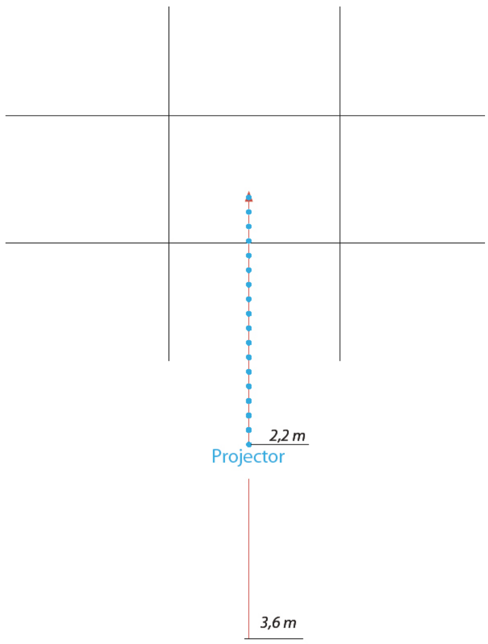


Figure 1. Scene settings for calibration and characterization of the digital projector NEC NP210.

2.1. Preliminary testing

Before conducting measurements a number of preliminary tests for defining projection conditions (the projection size in regard to the length of the room), for setting the i1Pro spectrophotometer to measure Screen luminance (Lv), for sighting, and picking the most appropriate projection module of the NEC NP210 projector, were performed. Our main purpose was to examine what happened to the digital projection measurements when using a projector in case of larger projection surfaces. That is why we used a spectrophotometer to test the gradation and color range from two measuring distances: the first one that fits the quadruple height of the projection (3.6 m) and the second that fits the position of the front lens on the lens of the projector (2.2 m). Color charts were projected not only in the Presentation module, but also in High Bright module and sRGB module, while the color range was determined in all six modules, thus also in Video, Movie and Graphic modules in order to chose the most appropriate module to create color profiles. On the basis of the obtained measurements and charts we found out that gradation differs according to the chosen projection module, and even more according to the measuring distance. Gradation in shorter measuring distance is much steeper and has lower luminance (Lv) of black (Figure 2).



2a

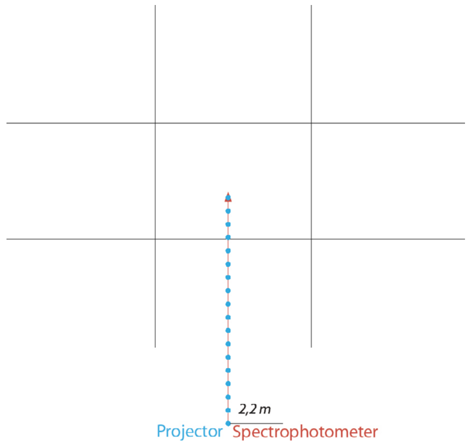


Figure 2. Gradation of the digital projector NEC NP210.

Color range of NEC NP210 digital projector differs in terms of the projection module and even more in terms of measuring distance. sRGB module reaches the largest color range, followed by Movie, then Video and Graphic; the finding applies both for the distance of 3.6 m and 2.2 m. The secondary colors at a distance 3.6 m are not placed on the side of the triangle, which can be best seen in the High Bright and Presentation modules. Likewise, the very same modules are most influenced by the measuring distance: the shorter the measuring distance, the larger the color range. In Figure 3 color range of the Presentation module is shown, measured at a distance of 2.2 m and 3.6 m. Secondary colors are no longer placed on the line segments of the additive triangle, which deforms into a plain hexagon.

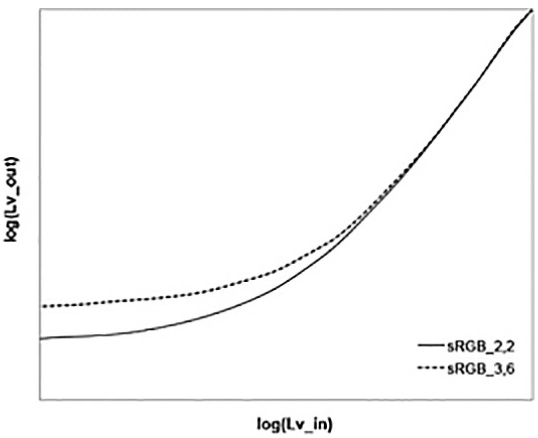


Figure 3. Color range of digital projector NEC NP210 the Presentation module is shown, measured at a distance of 2.2 and 3.6 meters in CIE 1931 x,y chromaticity diagram.

2.2. Selection of the Projection Module

Projection module, that is, the setting of the NEC NP210 projector, was chosen on the basis of the color ranges analysis. We searched for the largest and least variable color range or color space at a certain measuring distance when an instrument is placed above the projector in the parallel of the front lens of the camera lens. The second condition was screen luminance (Lv) of the white point, which could not be smaller than 110 cd/m², as the projector was characterized in the chosen module to get as close as possible to the standardized sRGB color space. It is based on the brightness of the white point 80 cd/m², which is why we used the remaining 30 cd/m² to the computer in order to perform the necessary corrections of the color space by using LUT charts.

Chromatic diagrams CIE 1931 x,y and CIE 1976 UCS (u', v') have shown that sRGB module has the largest color range. In Figure 4 the modules of the NEC NP210 digital projection are shown in the chromatic diagram UCS (u', v') at a measuring distance of 2.2 m, where it becomes clear that sRGB module has the largest color range.

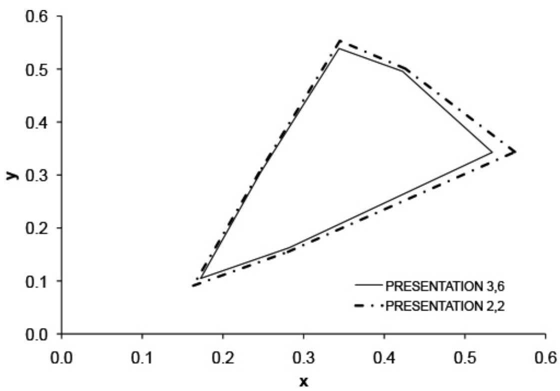
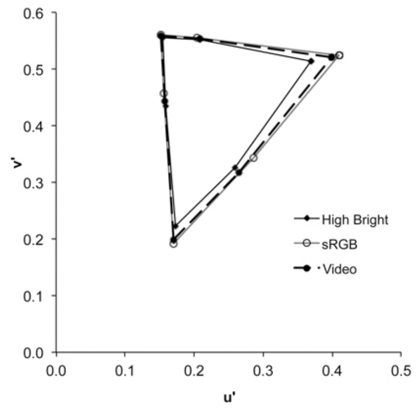


Figure 4. Color ranges of the NEC NP210 digital projection at measuring distance of 2.2 m; a) High Bright, sRGB and Video module; b) Presentation, Movie and Graphic module.

However, ISO 12646:2010 standard also anticipates evaluation in L*(C*uv) diagrams that show us how bright and saturated colors can be displayed. The measurements of the individual modules of the projector have shown that red R, green G, and yellow Y are best displayed in Video module, whereas blue B, cyan C, and magenta M are best displayed in Movie module. Cyan and yellow present the biggest problem;

the former is very low in saturation in Video module (Figure 5) and the latter in Movie module, which can be seen in Figure 6.

a



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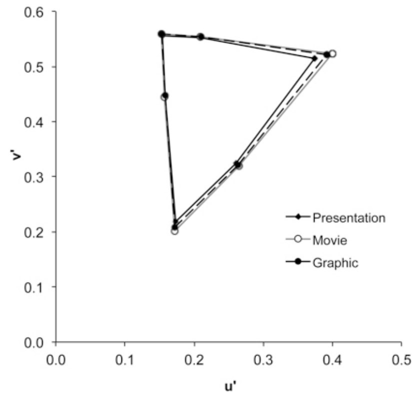

Figure 5. Brightness in a relation to chroma for the Cyan color of the projection modules of the digital projector NEC NP210.

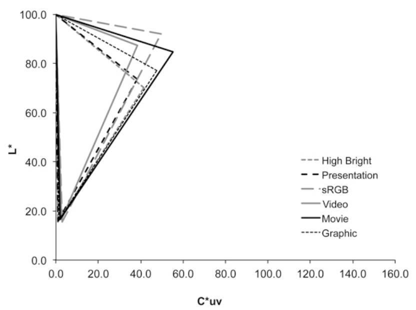

Figure 6. Brightness in a relation to chroma for the yellow color of the projection modules of the digital projector NEC NP210.

In the research screen luminance (Lv) of the white point, correlated color temperature and module sensitivity to changes (deviation) of the measuring distance were used. White point luminance (Lv) in Movie module is, in average approximately 6.5 cd/m² higher than in Video module. Correlated color temperature of the white point, that is, its location in the chromatic diagram CIE 1976 UCS (u', v'), is much closer to the desired white point D65 (the selected white point u'= 0.198 and v' = 0.468) in Movie module than in Video module. The measuring distance influences the decrease of the color range in Video module more than in Movie module. Hence, Movie module is the most suitable for the characterization of the NEC NP210 digital projector by using a i1Pro spectrophotometer.

The above findings were of vital importance for the continuation of the research and tests, as the measurements and the characterization are performed in a manner, where a spectrophotometer is always placed above the digital projector or below it, so that the measuring distance equals the projection distance. Thus the NEC NP210 projector is characterized in Movie module with the desired color profile according to the sRGB standard.

2.3. Colorimetric accuracy of the digital projector

After forty-five minutes of warming up the NEC NP210 projector, we first performed measurements of the uncharacterized projection (without the attached profile) in suitable sRGB and Movie modules. We continued with characterization of the chosen module by using the following combinations of measuring equipment and software: i1Match 3.6 application combined with i1Pro spectrophotometer, and basICColor display 4.1.22 application combined with i1Pro spectrophotometer. Before every measurement we projected a DPT-W315-T color chart (Figure 7) to the projection screen and with a visor the instrument was aimed at the centre of the central field 5 by using a target.

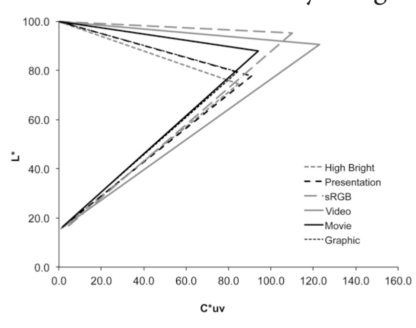

Figure 7. Color chart DPT-W315-T for accurately sighted the instrument before measurement.

The colorimetric accuracy of the digital projection was evaluated with 24 fields of the Color Checker Classic color chart. One after another, we projected color charts (Figure A and B) to the screen and measured CIEXYZ values of the central field on each of them (Figure 8). The color differences ΔE*ab between the displayed and reference values of Color Checker Classic chart was calculated.

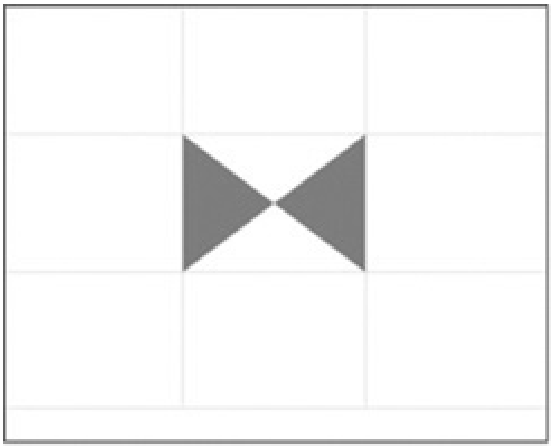

Figure 8. Field a) 19 white and field b) 23 neutral 3.5 of the Color Checker Classic color chart.

2.4. Colorimetric accuracy of computer screen and digital projector

Although ISO 12646:2010 standard determines the reference values of the colorimetric accuracy with the average of ΔE*ab 5 and maximum ΔE*ab 10, we wanted to test how well the display on high quality CRT and LCD screens fits them and compare the results to digital projection. With the available measuring equipment we first calibrated (basICColor display 4.1.22+i1Pro) the CRT Hitachi screen (21 inches) to the prescribed values according to the sRGB standard, i.e. correlated color temperature 6500 K and gradation and sRGB gamma respectively). Later on, we did the same with the LCD Eizo 242 screen, yet we chose the desired luminance (Lv) 90 cd/m² and also reached it. The quality of this profile was additionally checked by the UDACT software, which confirmed that the screen was capable of displaying all color spaces for the screen preview, as it was certified.

The 24 fields of the Color Checker Classic color chart were used for the evaluations and comparisons. One after another color charts were projected to the computer screen and CIEXYZ values of the central field on each of them were measured. Than the color differences ΔE*ab between the displayed and reference values of Color Checker Classic chart were calculated.

3 Results and discussion

Unlike the sRGB default module, we could not reach the same size of the color space by characterizing the Movie module, which is evident from the green color in the diagram L*(C*uv), shown in the Figure 9. Nonetheless, we have reached a slight enlargement of the color space in magenta and cyan colors, which is evident from the diagram L*(C*uv), shown in the Figure 10, using basICC display 4.1.22+i1Pro profile with magenta color (Movie+baICC label).

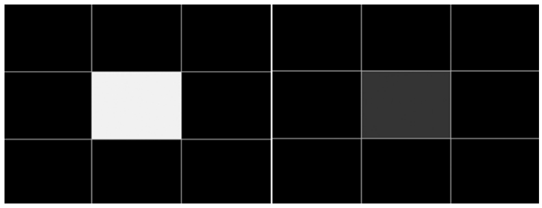

Figure 9. Brightness in a relation to chroma for the green color, Movie module of the digital projector NEC NP210.

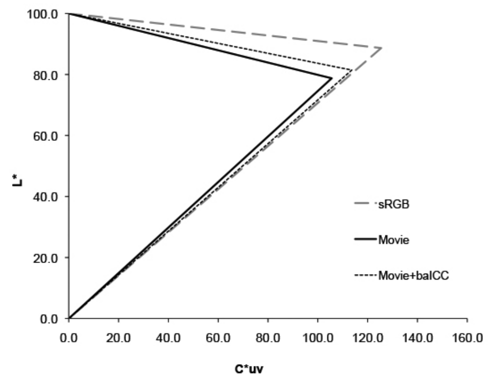

Figure 10. Brightness in a relation to chroma for the magenta color, Movie module of the digital projector NEC NP210.

3.1. Colorimetric accuracy of the digital projector

In Table 1, we can see the measurements results of the characterized Movie and sRGB modules, evaluated using the Color Checker Classic color chart and the i1Pro spectrophotometer. The display of the colors in the Movie default module is the worst with the average deviation ΔE*ab 11.4 and maximum deviation ΔE*ab 17.82.

The test performed with spectrophotometer using applications i1Match 3.6 and basICColor display 4.1.22 improved the uncharacterized projection in Movie default module. The color differences using the i1Match 3.6 application are larger than in the sRGB default module, but averagely much better when using the basICColor display 4.1.22 application; the ΔE*ab is still too large (17.28) in cyan color, which cannot be displayed well by the standardized color space sRGB by definition.

From the results obtained and preliminary tests performed it can be concluded that i1Pro spectrophotometer gave inconsistent results at emission measurements of the projected colors, which can best be seen in determining gradations and color ranges. Measurements inconsistency intensifies according to the measuring and projection distance or size and screen luminance (Lv) of the projection surface respectively. The reason for this lies in the problematic sighting of the very instrument, even though we used a geodetic level. Performing measurements with i1Pro spectrophotometer are best carried out when the measuring distance equals the projection distance. A more precise laboratory instrument (without any problems regarding sighting) would be needed for colorimetric evaluation (and characterization), such as the most recent instrument, basICColor DISCUS. The combination of i1Pro spectrophotometer and basICColor 4.1.22 application worked best with characterization, yet an independent laboratory instrument for color display control would be a valuable acquisition. Color Checker Classic color chart in digital form according to the projected color space

Table 1. Measurements results of the characterized Movie and sRGB modules, value ΔE*ab of less than 5, are marked gray.

Color Checker Classic	Measurements ΔE*ab whit i1Pro				
	Movie	Movie	Movie	sRGB	sRGB
		i1Match 3.6	basICCcolor display 4.1.22 + i1Pro (Lv=100)		basICCcolor display 4.1.22 + i1Pro (Lv=100)
Dark skin	7.55	5.59	8.81	5.60	8.96
Light skin	11.13	5.97	9.93	4.83	10.64
Blue Sky	9.74	4.14	5.72	3.03	7.27
Olive Green	11.54	0.78	6.43	1.69	8.73
Violet	9.35	4.88	7.07	4.03	7.54
Bluish Green	11.53	9.11	11.69	6.86	15.65
Orange	15.75	10.19	16.25	8.48	16.67
Purplish Blue	11.71	5.64	4.98	3.45	5.86
Moderate Red	5.35	9.94	16.14	9.55	15.39
Purple	7.59	6.62	10.40	6.58	9.26
Yellow Green	16.41	5.26	9.79	4.24	14.46
Orange Yellow	17.82	8.85	13.34	6.94	15.19
Blue	13.98	5.75	4.99	3.09	7.55
Green	14.62	7.83	11.76	8.93	17.66
Red	3.57	11.49	18.80	10.49	17.07
Yellow	16.82	7.51	11.82	6.37	15.32
Magenta	11.63	10.40	14.36	10.47	17.54
Cyan	16.49	16.28	17.28	11.87	17.57
White	9.99	3.39	7.08	3.51	14.85
Neutral 8	11.82	2.87	5.96	3.33	12.65
Neutral 6.5	11.67	2.24	6.29	2.20	9.90
Neutral 5	10.02	3.07	6.11	2.54	7.12
Neutral 3.5	6.24	2.76	7.74	3.42	3.88
Black	5.09	6.03	12.40	5.59	1.33
all colors					
Mx1 ΔE*ab	11.14	6.57	10.21	5.57	11.59
Max2 ΔE*ab	17.82	16.28	18.80	11.87	17.66
Tones					
Mx[1] ΔE*ab	9.14	6.57	7.60	3.43	8.29
Max[2] ΔE*ab	11.82	16.28	12.40	5.59	14.85

Mx1 - average value; setpoint ΔE*ab = 5, Max2 - maximum value; setpoint ΔE*ab =10 is sufficient in terms of control. According to the ISO 12646:2010 standard, control and evaluation of the digital projection are relatively complicated and time consuming.

3.2. Colorimetric accuracy of computer screen and digital projector

In Table 2 we can see the results of the colorimetric accuracy of the computer screen and digital projector measurements. From the results obtained it can be discerned that both computer screens match the standards at a direct display of Color Checker sRGB color chart by using Microsoft Power Point and sRGB system profile. Nonetheless, even a NEC NP210 projector with sRGB default module without profile in studio conditions can work out when necessary. All in all, digital projection displaying a standardized sRGB color space is not comparable to a high quality CRT or LCD computer screen.

4 Conclusions

According to a ISO 12646:2010 standard, digital projection and the examined projector are incomparable to the display of high quality CRT or LCD screens.

Table 2. Colorimetric accuracy of the computer screen and digital projector measurements, value ΔE*ab of less than 5, are marked gray.

Color Checker Classic	Measurements ΔE*ab whit i1Pro			
	Module Movie	Module sRGB NEC NP 210	Computer screen EIZO	Computer screen Hitachi
	i1Match 3.6	Without profile	BasiCC_sRGB /UDACT	BasICC_sRGB
Dark skin	5.59	5.60	6.05	4.53
Light skin	5.97	4.83	3.62	3.31
Blue Sky	4.14	3.03	2.95	4.38
Olive Green	0.78	1.69	4.35	5.01
Violet	4.88	4.03	2.42	3.35
Bluish Green	9.11	6.86	2.53	5.16
Orange	10.19	8.48	4.73	2.69
Purplish Blue	5.64	3.45	4.15	4.47
Moderate Red	9.94	9.55	3.70	2.79
Purple	6.62	6.58	3.84	3.96
Yellow Green	5.26	4.24	4.71	5.94
Orange Yellow	8.85	6.94	5.3	4.10
Blue	5.75	3.09	4.5	5.08
Green	7.83	8.93	4.29	6.30
Red	11.49	10.49	4.34	2.67
Yellow	7.51	6.37	5.75	5.14
Magenta	10.40	10.47	2.71	3.72
Cyan	16.28	11.87	2.51	3.78
White	3.39	3.51	3.66	4.33
Neutral 8	2.87	3.33	2.98	3.87
Neutral 6.5	2.24	2.20	2.63	3.38
Neutral 5	3.07	2.54	3.01	4.00
Neutral 3.5	2.76	3.42	4.36	4.47
Black	6.03	5.59	8.22	7.16
all colors				
Mx1 ΔE*ab	6.57	5.57	4.05	4.34
Max2 ΔE*ab	16.28	11.87	8.22	7.16
Tones				
Mx1 ΔE*ab	6.57	3.43	4.14	4.61
Max2 ΔE*ab	16.28	5.59	8.22	7.16

Mx1 - average value; setpoint ΔE*ab = 5, Max2 - maximum value; setpoint ΔE*ab =10

We predicted that the colors in characterized color projection would display more accurately than without characterization; unfortunately, quite the opposite often happened. Also, a new color profile had to be created for each projection distance and the screen. Projection distance is standardized and specified with the height of the projection surface, while the screen and other projection circumstances influence the results achieved substantially.

Precisely the selection of the suitable default module, either for a direct projection or color management, is the main problem. Gradation and color gamut testing do not enable the differentiation of quality of neither projection modules, or color profiles. Colorimetric accuracy evaluation by using a digitalized Color Checker Classic color chart is the only that produces useful results, especially if we separately examine the chromatic colors display with a focus on skin tones and achromatic colors with a focus on grey balance and chromaticity respectively.

Considering that semi-professional and professional projectors are very expensive devices, color management with a instrumental calibration and characterization (the same goes for screens of better quality), are a favorable prospect. Thus we do not need a number of unsuitable projection modules and settings, used for experimenting without reaching good results. It is not sensible to characterize digital projections for the purpose of house, office or average school use. It is best to choose the projection module one fancies the most and correct it on the basis of the Color Checker Classic color chart visual grade and other testing figures according to the projector's performance. For this purpose, the software and measuring instruments should be improved significantly. Present equipment is best used merely for colorimetric analysis and characterization of the studio projectors in the selected projection module and color space.

In order to make digital projection equivalent to the color display on certified computer screens, we need a suitable standard (ISO) that would deal with digital projection only, a reliable instrument with suitable software support for credible measurement and characterization, application for a quick incontestable choice of a projection module and a reliable digital projection certification, professional digital projectors without a number of projection modules and settings, but with efficient mechanical calibration based on desired display.

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