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Methodology and Tools for Quality Verification and Measurement Interpretation in a Digital Cinema Environment

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Abstract

In this paper, we present a set of methodologies for Digital Cinema projector calibration, quality verification and evaluation by application of the international visual test SMPTE Digital Projection Verifier (DProve) as well as related SMPTE and ISO standards. We demonstrate modified SMPTE guidelines for faster, simpler and more precise measurements in practical conditions and introduce several tools for illustrative quality evaluation. The measurement interpretation is based on both, absolute tolerances defined by the SMPTE standards, as well as relative assessment calculated by the CIEDE2000 color difference formula. The latter approach is intended to better understand the importance of the color and tonality error for viewer's perception in the specific cinema low light levels. On the examples of selected D-Cinema projector and display measurements, we introduce possible strengths and weaknesses of various projection technologies, used in Czech and Slovak commercial cinema or review rooms, which differs by the specific manufacturer's technology or type of light source.

Introduction

Digital Cinema Initiatives (DCI) has been originated as a joint venture of the seven major motion picture studios in 2002 to establish projector and its viewing environment. The goal was to specify global quality standard for motions pictures digital screening (D-Cinema) visually comparable to that 35mm one, regardless of the D-Cinema projector's chipset technology (open standard Texas Instrument's Instrument Digital Light Processing or Sony's proprietary Silicon X-tal Reflective Display), kind of manufacturer's light engine and lightpipe (Barco, Christie, NEC, Sony) or lamp (xenon, uhp, laser).

The first prototype of D-Cinema projector with DLP 3 chip projector had been demonstrated at Hollywwod in 1997 and the first film "Star Wars: Episode I" (1999) was released experimentally on two digital cinema screens in New York and Los Angeles after two years. D-Cinema technology has been pushed away electronic cinema systems (E-Cinema dataprojectors) from the theatres along the fall of film stock manufacturers or labs. The next years SMPTE adopted several standards, best practice and engineering guidelines to specify D-Cinema mastering, distribution and projection environment.

The specification of the Digital Cinema Environment has been improved several times since the intention was to achieve the greatest possible match with the film projection. The reference luminance was chosen 48 cd/m^2 as standard 35mm film open gate luminance 55 cd/m^2 minus film base. Secondly, the reference white point was chosen specifically and not the same as D65 for high-definition television according to the ITU Rec. 709 standard. While the spectral output of dominant xenon light source in 35mm projector does not vary that much [12], the white points of film projectors around the world vary a lot as it has been proven during survey made by Glenn Berggren and THX until 2001 [10]. The reason why is the color characteristics consist not only of xenon lamp itself but of the screen or port glass item. Therefore, reference white point for the digital cinema (DCI-P3) was chosen in the center of the scatter plot representing current practice and the most efficient operation point for the Xenon lamps with chromaticity coordinates $x = 0.314$, $y = 0.351$.

This standardization initiative introduced the sophisticated image tests called SMPTE D-Cinema Digital Leader (Digital Leader) and SMPTE Digital Projection Verifier (D-Prove) [6], that are not suitable only for audio stream synchronization but also for quality image analysis and verification. Digital Leader is available in XYZ color space (12 bits per pixel) as uncompressed .tif images sequence in the form of Digital Cinema Distribution Master (DCDM) for mastering. D-Prove is available in CIE XYZ color space as compressed jpeg2000 files that are wrapped in .mxf generic container in the form of Digital Cinema Package (DCP) in RGB-P3 space which is intended for theatric distribution. Both image sequences include 192 countdown frames in duration on the same special single visual background with numbers of testing image elements for objective measurements as well as a couple of the other patches for simple subjective visual assessment (e.g. by Kodak glass filters). The purpose of that D-Prove image test pattern is to evaluate compliance with predefined maximum photometric and colorimetric deviation from the reference projector in two quality levels: for review room and commercial theatres as written in the standards published by SMPTE [1, 2, 3, 4] and ISO [5].

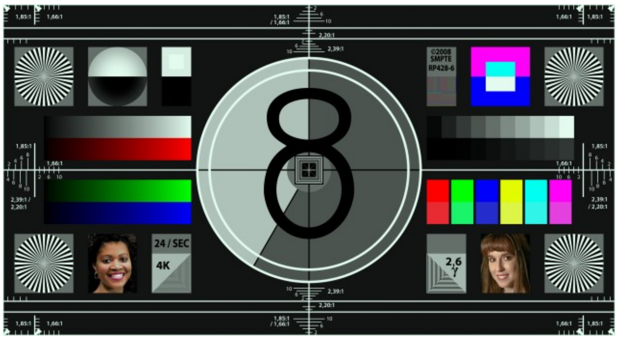

Figure 1. *The example frame of the SMPTE Digital Projection Verifier (D-Prove, available as the Digital Cinema Package, DCP, in 4K .jpeg2000 codestream in visual lossless compression and wrapped into .mxf generic container) and SMPTE D-Cinema Digital Distribution Master Headleader (Digital Leader, available as the Digital Cinema Distribution Master, DCDM, in 4K .tif file image sequence). Both are defined by the SMPTE written standard RP 428-6:2009.*

Unfortunately, these standards are quite unknown and are practically not used across Europe despite the woes over the uneven quality of the projected image and the fact that local state funds subsidize cinema digitization by partial contribution if it complies with the international standard. One reason for this may be that open industry DCI specification referred to the standards published by SMPTE (Society of Motion Picture & Television Engineers) or ISO (International

Organization for Standardization) which describe in particular D-Cinema content encryption, compression, space resolution or playback. Until recently it has been published DCI specification version 1.3 (June, 2018) which finally contains explicit mention of the specific SMPTE color and luminance standards mentioned above.

Until now, about 40 thousand digital cinema screens in Europe and more than 160 thousand worldwide have been installed [9]. But how many of them really meet the SMPTE and ISO standards? It can be hardly verified. This question may be all the more important for the countries with low digital penetration and future need for next cinema digitization in the future. Although it might require significant effort, the intention of the standards as well as our research is validate the promise of digital cinema to deliver to audiences a technically accurate image that faithfully reproduces the filmmakers' creative intent.

Problem description

The above mentioned SMPTE recommendations [3] and engineering guidelines [2] describe and the image test [1] include, besides others, thirty two evaluation figures. Firstly the set of quite small horizontal twenty shade of gray step scales (black-to-white nr. 17 and black-to-dark gray nr. 18). Secondly it includes six primary and subtractive D-Cinema RGB-P3 full saturated color patches nr. 19 and six primary and subtractive HDTV ITU-R BT.709 full saturated color patches nr. 20.

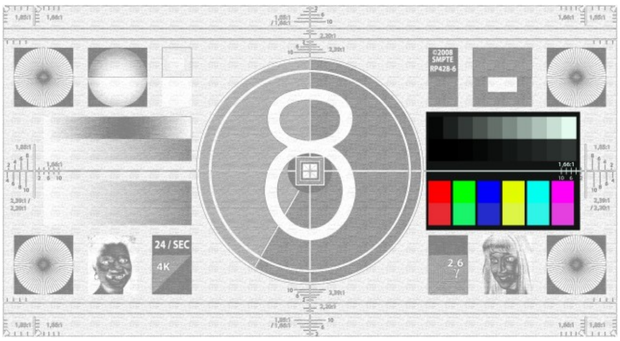

Figure 2. *The example frame demonstration of the SMPTE RP 428-6:2009 D-Prove and DCDM Digital Leader. Two sets of ten step scales nr. 17 (black-to-white) and nr. 18 (black-to-dark gray) above. Below two series of six vibrant (nr. 19) and six pastel (nr. 20) color patches.*

These test image elements have defined normative photometric and chromaticity coordinates (x, y) with given tolerances in the three particular quality levels. The zero for reference Digital Cinema projector. The next quality level represents ± 3.5 cd/m^2 luminance and ± 0.002 chromaticity deviation from the SMPTE and ISO standard [4, 5] for review rooms. And finally the lowest quality level defines ± 10,2 cd/m^2 luminance and ± 0,006 chromaticity tolerance deviation for projectors used in regular commercial theaters after the same standards.

These image characteristics should be measured by spot photometer and spectroradiometer devices as the reflection from the screen under specified criteria [4, 5]. The reference measuring device having the spectral luminance response of the standard observer shall by a spot one with acceptance angle 2° or less. The photometer shall have and accuracy of ± 0.5 cd/m^2 and the angle 2° or less. The reference spectroradiometer shall have an accuracy of ± 0.5 cd/m^2 and better.

We found during previous research project [8] by the very first measurement of a special D-Cinema postproduction projector Barco DP4K-P that actually such state-of-art device might not fully comply with mentioned SMPTE standards for specific conditions. That is why we have been firstly asking how important are really measured color and luminance differences for viewer's perception in a commercial theater on the one hand. On the other hand it may be more important in a review room where evaluation during color grading, film restoration or approval screening of archival films is critical. Particularly in view of the fact that in the screening room luminance levels between tens to hundredths of cd/m^2 occurred, often not photopic but mainly mesopic vision somehow applied. Likewise the absolute threshold of cone vision and its importance for color discrimination as well as the rod contribution to chromatic aspects of vision was underestimated until recent researches [7]. And the mesopic luminous efficiency function is not accepted yet.

Anyway, at low luminance levels, the threshold of the visibility of the color difference may decrease. The Annex L of the relevant SMPTE Engineering Guideline [2] recommended higher importance of perceived color difference calculated from the test pattern measurement under a few tenths of cd/m^2 (cca six black-to-dark steps nr. 18/1 till 18/6 with the lowest luminance and the darkest black-to-white step nr. 17/1). Is it really negligible or, on the contrary, significant not only for the cinema viewer but also for the filmmaker in the review room? However, the color difference formula ΔE*ab used by the SMPTE body "*is not appropriate for assessment of the color errors produced by a system*" as commented by the authors. We prefer using the color difference formula ΔE*00 during this study whereas it has been shown in our previous research [8] it is suitable for perceptually uniform evaluation of color differences in homogenous areas.

Secondly, we asked how various projection technologies, including not only Digital Light Processing (DLP) and Liquid Crystal on Semiconductor (LCoS) projectors with RGB or phosphor-laser light source but also D-Cinema dedicated postproduction liquid crystal displays (LCD), differs in terms of quality compliance to the international theater standards. That is why we tested different Central European venues where digital screens penetration is low in comparison to other western or northern European countries.

Slovakia (cca 70%) or in Czech rep. (cca 50%) has achieved noticeable one of the lowest digital cinema screens penetration in Europe [9] since the digitization has being late and high numbers of monoscreens predominate. Furthermore, the curiosity of Czech rep. is increasing number of open-air cinema or multi-function centres where D-Cinema technology has being adapted but it start to be pushing out from the market by the E-Cinema now. Including, but not limited to the Czech government has contributed almost 150 million to digitize cinemas from the Czech Film Fund. And how many of them meet the SMPTE and ISO standards? Until now, more than 500 digital screens have been installed in Czech rep., where new born films have been theatrically distributed only in digital last five years. Only less than one fifth of the total numbers of Czech cinema used 4K technology at present.

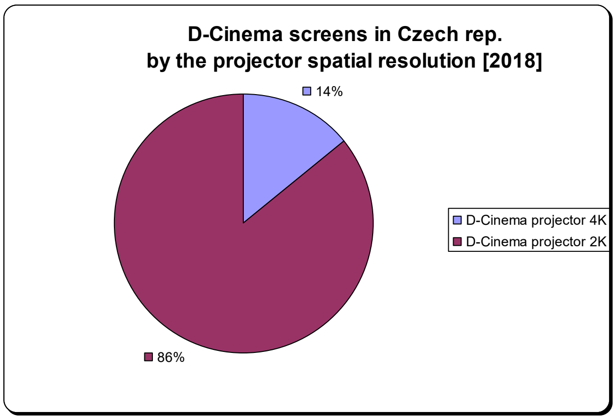

Figure 3. Commerical D-Cinema screens in Czech rep. by the projector spatial resolution in 2018.

The statistical visual representation of various manufacturer's technology including projector's chipset type, different light engine, light pipe or lamp, we created based on public information [13], is visible on the following figure. Prevailing manufacturers with the main market share are Barco/Kinoton and Christie that prefer DLP chipset with xenon or laser light source. Whereas Sony as the only one manufacturer using SXRD chipset has minor market share similar to NEC. They both are also specialized to small venues and so they produce projectors with UHP light source too.

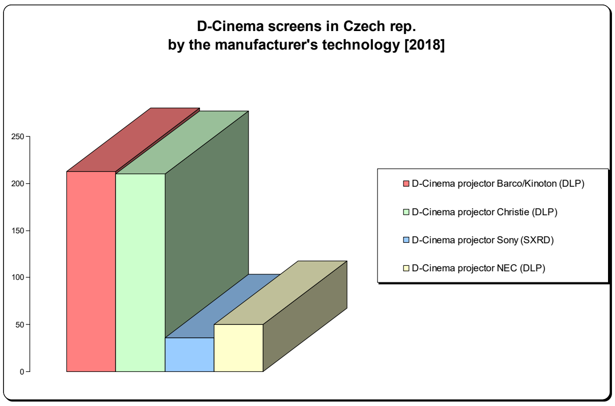

Figure 4. Commerical D-Cinema screens in Czech rep. by the projector manufacturer's technology in 2018.

Whereas not only Czech or Slovak digital born films are exploited in our cinemas but also new foreign blockbuster or approval screenings of restored films in different review rooms there cannot be ignored. The quality of the premiere or festival screening may also affect the overall acceptance of the movie by a journalist or the jury's rating at an international film festival.

That is why a simple, fast and still accurate digital cinema measurement workflow and illustrative image quality evaluation is desirable.

New full-field test images and workflow

With regards to the economical situation and technical equipment of various cinema sites and review screening rooms in our region we consider developing the set of full-field test images as well as modifying the above-mentioned SMPTE engineering guideline for faster, simpler and more precise measurement workflow. The innovative procedures were as follows:

1. Creating thirty two DCDM test images in CIE XYZ color space;
2. Encoding them in .jpeg2000 codestream and wrapping them in unencrypted DCP file in RGB-P3 space;
3. Preparation of Microsoft Excel data form in which the numeric evaluation is automatically calculated;
4. Preparation of universal and portable DCP player system that enable playback without D-Cinema media server;
5. Selection of representative commercial cinema and review rooms in Czech rep. and Slovakia.
6. Each selected projector image quality verification and calibration according to the international standard.
7. Measuring photometric and colorimetric coordinates of each projector by reference device.

First of all, we produced set of full-field test frames in Matlab programming environment, according to SMPTE standard [3]. These full-field images (DCDM compatible) in flat (1:1.85) and scope (1:2.39) ratio enable faster and simpler inter-frame sequential measurement even with a wide-angle spectrophotometer compared to the original intra-frame D-Prove measurements which is depending on the precise position of the measuring device, photometer and spectroradiometer angle or projection screen size, reflection angle and overall quality. Advance of the series of thirty two new full-field test images in 4K resolution compared to the one original and complex SMPTE one with many step scales and patches is evident. The new one single test pattern fills the entire screen and enable faster, simpler and more precise measurement even with a wide angle spectrophotometer, whereas the SMPTE one occupies only units of percent of the entire screen.

Figure 5. Simulation of twenty single full-field test images from nr. 17/1 to nr. 17/10 (black-to-white steps) and from nr. 18/1 to nr. 18/10 (black-to-dark steps) which are transformed for demonstration into sRGB color space with the adaptation to DCI-P3 white point.

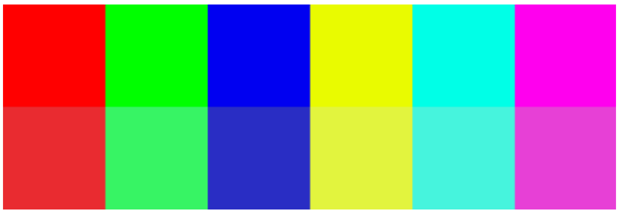

Figure 6. Simulation of single full-field test images from nr. 19/1 to 19/6 (full saturated primaries and secondaries in RGB-P3 color space) and from nr. 20/1 to nr. 20/6 (full saturated primaries and secondaries in ITU-R BT.709 color space) which are transformed for demonstration into sRGB color space with the adaptation to DCI-P3 white point.

Secondly, we encoded .jpeg2000 codestream in visual lossless compression in 4K of the new full-field thirty two DCDM single test images and wrapped them into .mxf generic container to create unencrypted flat and scope DCP in RGB-P3 color space.

Third, we prepared the MS Excel data form with formula which allows automatically evaluate both the photometric and colorimetric deviation in three quality levels (reference projector, review room, commercial cinema). It allows an evaluation in the absolute numbers or by the relative levels in respect to the standard [1] (percentage share with reference 100% in the case of luminance evaluation and simple difference with reference at 1 in the case of colorimetric one).

Fourth, we prepared and tested universal portable DCP playback system which compose of the portable universal player (Blackmagic Ultrastudio for Thunderbolt 4K Extreme 3) with dual-HD-SDI outputs and the powerfull laptop with CUDA GPU for .jpeg 2000 fast decoding with non-dedicated DCP software player (IIS Fraunhofer EasyDCP+). This system eliminates possible measurement differences by using various D-Cinema players as well as enables to playback test DCP at the review rooms where media server may not been present. Moreover, the playback system allows output in both direct CIE XYZ and common RGB-P3 color space as it turns out to be ideal for different D-Cinema projector verification and calibration.

Fifth, we selected several D-Cinema projector of different generations that were installed both at the review rooms and commercial theatres in Czech rep. and Slovakia our region. The rule of the selection was to represent at least one of the following projection D-Cinema technology. That is why it includes DLP or SXRD chipset; Barco, Christie, NEC or Sony light engine as well as lightpipe technology in first and second generation; all the three kind of light source xenon, uhp, laser.

Sixth, we took each time on-site measurements of the screen chromaticities of red, green, blue, white and exceptionally black proprietary test pattern to obtain measured color gamut data (MCGD) as the base of not only calibration of the projector with a diminishing lamp over time, but the whole Digital Cinema Environment, which also consist of port window, screen or ambient light. Then, we put the data in the projector software which compared them to the target color gamut data (TCDF) for enhanced color correction in P7 space that provides capability for the calibration of not only the three projector primaries and white, but also the placement of three secondary colors (cyan, magenta and yellow). This sophisticated system of each D-Cinema projector calibration computes a compensating color matrix as well as enhancing the color space for more natural skin tones. As Matt Cowan from Texas Instruments explained: "*Yellow should be a combination of red plus green, but in order to get bright enough yellows, we had to crank the red and green brightness too high. What we did in the P7 world was reduce the target luminance of the red and the green but left the target luminance of yellow high. In fact in P7, we can get very bright yellows without getting very bright greens or reds associated with it* [11]."

Seventh and finally, we measured photometric data and chromaticity coordinates for 2° CIE 1931 observer using above mentioned DCP test images and playback system in selected D-Cinema venues by the reference spot device Photoresearch PR-740 with viewing angle 2° or less. While we fulfilled the condition defined by the SMPTE standards which means we took it at the center of the seating row and closest to the geometric center of the seating area at height around 1.1 m above the floor as well as keep no stray light on the screen exceeding normal viewing condition [3], [4]. Since our applied research and experimental development does not focused on perceptual uniformity of the image screen and we used self-made full-width test images, we can shorten the measurements by performing each one at the geometric center of the screen only.

New tools for quality evaluation

We developed several tools in the MS Excel environment for illustrative quality evaluation and interpretation of aggregate various measurements of the selected Digital Cinema environments. First of all the multiple bar charts and secondly the special polarograms (polar diagrams). Both of them evaluate luminance and color deviations from the standard tolerance in two quality levels for review room and commercial cinema.

At the beginning see the bar chart example showing measured luminance of all the 32 single test images as the example of the oldest D-Cinema 4K projector in the test made. The Sony SRX-R320 based on SXRD three 1,55" chip technology with Xenon lamp was installed at the art house cinema. The pink highlight shows the tolerance for the commercial cinema and the dark red for the review room. Short dark line with the measured luminance numbers on the bar head shows the spot photometer Photoresearch PR-740 accuracy tolerance published the manufacturer. It can be seen that such device accuracy is definitely negligible with respect to the measurements as well as two quality levels tolerance defined by the above mentioned standards.

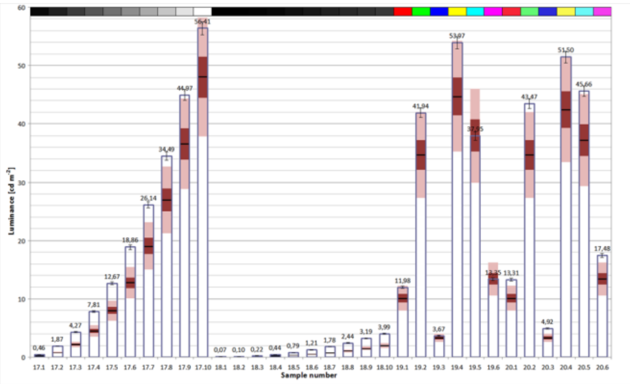

Figure 7. *Measured luminance of all the 32 single test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector Sony SRX-R320 with indication of the tolerance from the standard in two quality levels (cinema and review room).*

The next bar chart showing relative luminance share in % to the 100% reference (48.02 cd/m^2) of the Sony SRX-R320. That shows the projector fulfill the review room quality level tolerance on the test image 19.5 (RGB-P3 cyan) and 19.6 (RGB-P3 magenta), while only two grey steps fulfill the commercial cinema quality level tolerance. All the other grey steps are completely out of limit, some even more than 300% from the reference.

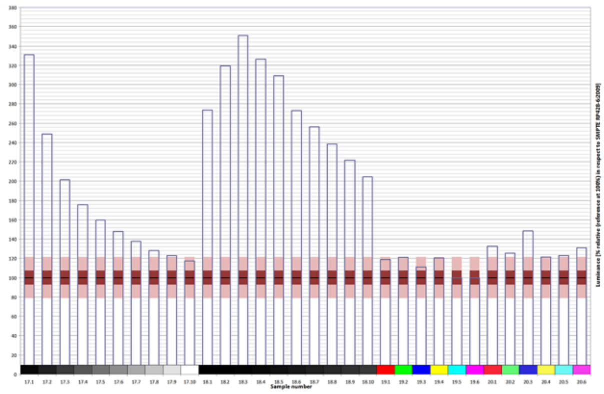

Figure 8. *Relative luminance share in % to the reference of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector Sony SRX-R320.*

The next figure shows colorimetric deviations from the standard of the Sony SRX-R320. The chromaticity coordinate "x" is represented by the violet color and coordinate "y" by the soft green. As we can see, only test image 19.1 (RGB-P3 red) meets the standard. The lowest luminance black-to-dark grey steps drop out of range towards cyan or even green tones.

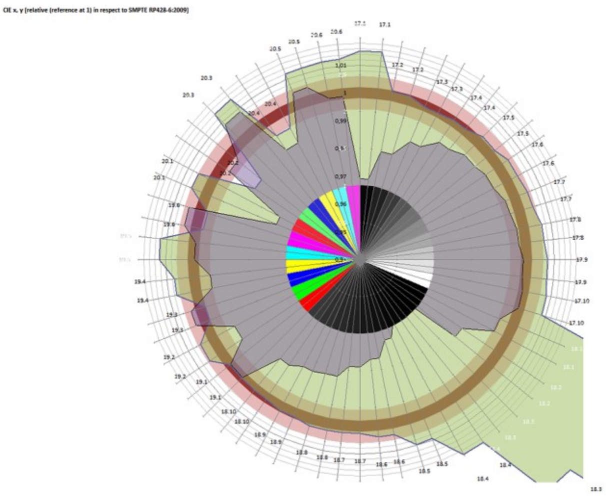

Figure 9. *Relative chromatic deviation (x coordinate in violet, y in green) as difference from the reference at 1 of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector Sony SRX-R320.*

The SXRD projectors generally used to have the problem with color uniformity if not regularly maintained and calibrated, which in particular sometimes creating color spots on the large screen when projecting black-and-white movies [14]. But the previous example of the SRX-R320 does not mean that all the Sony projectors are bad. It is just an example of a particular installation where cinema operators expected replacing of the projector in the future because further calibration could not improve the image quality.

Advanced and illustrative quality evaluation

In short, the polar diagram resembles an apple. If it is not bitten, then the projector is quite good. But in other case such cinema is not for paying viewers and if exists, they should give them back money for movie tickets.

But let us get back to the Sony projector. We discovered during our communication with local supplier and service center that we can also diagnose various defects with our polar diagram. The circumstance indicates that the fault may be caused by shifts or impurities on the second dichroic mirror diving the light into green and blue light.

Other selected 2K projector NEC NC1000C based on three 0.69" DLP chip technology with UHP lamp was installed at the another commercial cinema which shows especially archival films. We observed new problem during calibration process because this projector offer one or double 320W lamps configuration. The maximum light output by projection of our flat test DCP in two UHP bulbs setup reached almost 70 cd/m^2 that is out of tolerance even for commercial theatre. On the other way, the setup with one UHP lamp does not reach 40 cd/m^2 in luminance. The cinema integrator claimed the art house used to screen more archival films in scope format. Whereas it causes about two thirds of light loss, he preferred to keep the configuration with one lamp only. Another interesting finding was the fact that the spot photometer X-Rite Hubble, used by the integrator, measured by 5 cd/m^2 more on the DCI-P3 reference white compared to our reference PR-740. The reason why may be the device does not meet standard [4, 5] and its calibration expired.

The next two figures show the measurement results of such projector with flat DCP. As we can see on the first figure, the luminance is quite balanced but too high compared to the reference luminance. The tonal gradation is poor on three lowest luminance black-to-dark steps compared to the previous Sony projector.

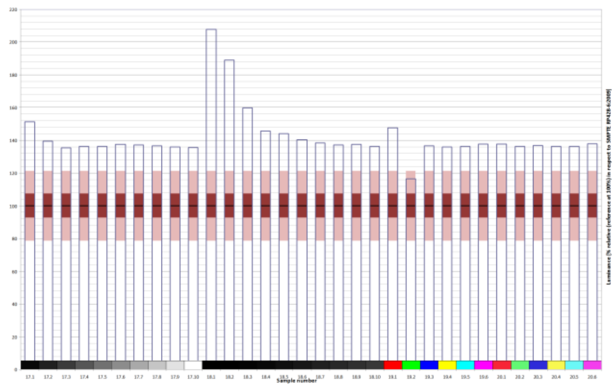

Figure 10. *Relative luminance share in % to the reference of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector NEC NC1000C*

Next figures show chromatic deviations from the standard in the case of NEC projector with both primary red and a little bit green shift to yellow tones.

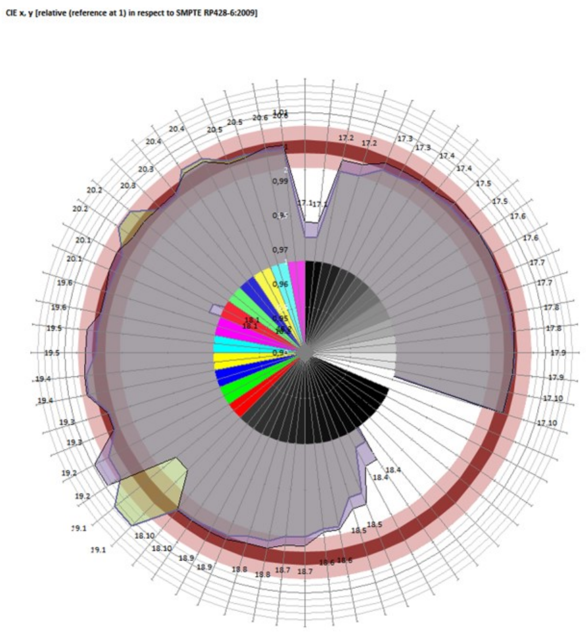

Figure 11. *Relative chromatic deviation (x coordinate in violet, y in green) as difference from the reference at 1 of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector NEC NC1000C*

Following figures show photometric and colorimetric quality of the Barco DP4K-17BLP based on three 0.96" DLP but with laser-phosphor light source. We were asked for quality evaluation by the postproduction company who consider this

4K device as the review room reference projector for digital restoration and mastering of the archival films.

On the next figure is visible that laser-phosphor projector is the first of the tested to absolutely meets the luminance parameters for commercial cinema and besides some lowest luminance steps as well as primary red and blue it fulfill luminance criteria for review room item.

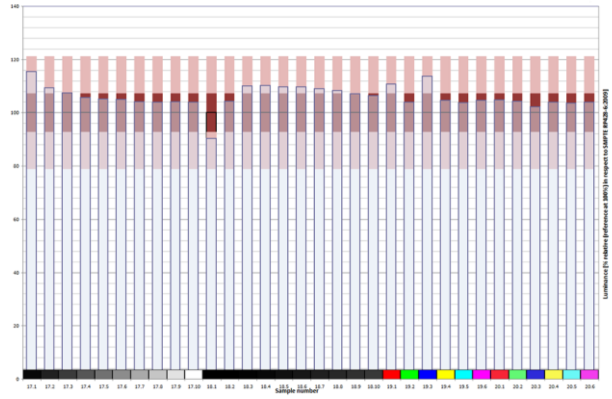

Figure 12. *Relative luminance share in % to the reference of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector Barco DP4K-17BLP*

However, the colorimetric parameters are not fulfilled as visible in the figure below. Four black-to-dark steps shift to cyan tones and the darkest black-to-white step shift to magenta shades. Then, primary blue shift to cyan too but primary red goes to orange or even yellow tones.

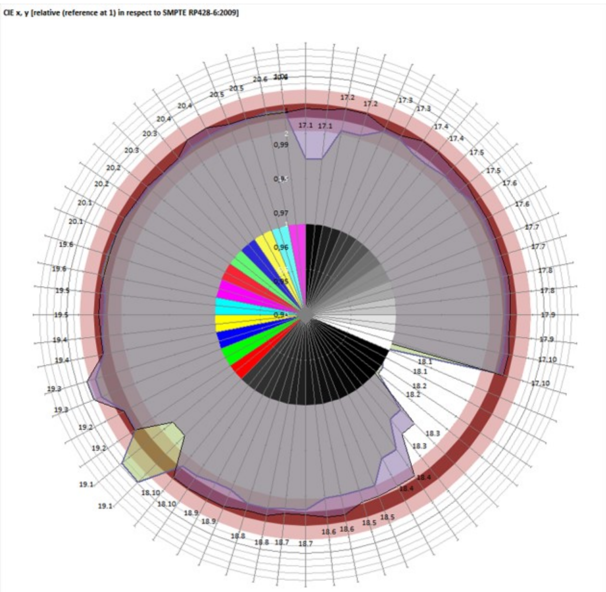

Figure 13. *Relative chromatic deviation (x coordinate in violet, y in green) as difference from the reference at 1 of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector Barco DP4K-17BLP*

Even though objectively, black-to-white steps are besides the darkest one perfectly fine in terms of compliance with the standard. Paradoxically, the disadvantage of such introduced bar charts and polarograms may be their analytical value in comparison to the complexity and syntheticity of human vision. We can demonstrate it on the thumbnail photo of the side by side two different D-Cinema projectors comparison. The laser-phosphor Barco DP4K-17BLP projector right and Barco DP4K-P postproduction projector with xenon lamp left. We can see specific shift to yellow tones in the case of Barco projector with laser-phosphor lamp even on the white or light grey complex images as the motion picture frames or still photos are. This proves the importance of subjective assessment by experienced observers as complementary tool for each objective measurement.

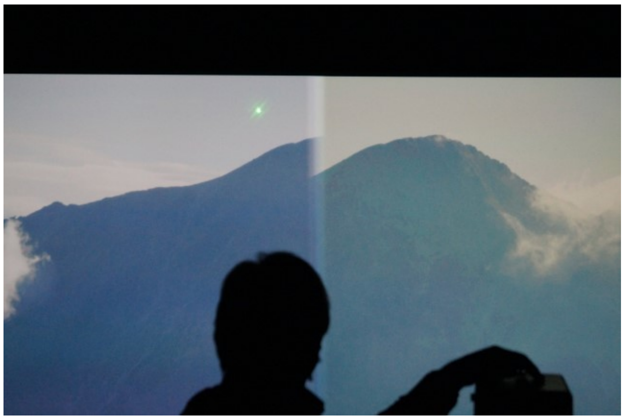

Figure 14. *Side-by-side comparison of the D-Cinema xenon projector Barco DP4K-P left and the laser-phosphor projector Barco DP4K-17BLP right.*

This experience can be attributed to a phenomenon well known as metamerism. And it could be objectively explained by the next figure showing quite continuous spectral radiance of the xenon left Barco projector (light brown line) compared to little bit more discrete (peaky) spectrum of the laser-phosphor right Barco projector (red line) with the peak visible in deep blue or indigo spectrum.

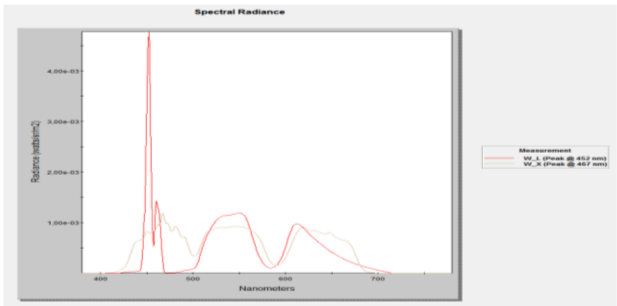

Figure 15. *Spectral radiance comparison of the D-Cinema xenon projector Barco DP4K-P left and the laser-phosphor projector Barco DP4K-17BLP right*

CIEDE 2000 for low luminance images evaluation

Following figure show colorimetric quality of the last 4K projector Christie CP4420 based on three 1.4” DLP with xenon light source. This new model of the middle price range projector was intended for installation at another postproduction house. The calibration process enables besides native projector primaries and white native black projector setting too. The integrator devoted unusual care to set the projector’s lens and xenon bulb in the lamp house by several mechanical procedures to get best Digital Cinema Environment setup. He used 3kW lamp with small mechanical iris from different special large venue dataprojector to reach optimal luminance but to get best image uniformity and color distribution he had to set the minimum lamp current. Thanks to this care the best match with colorimetric parameters appeared on all the color patches as visible on the next figure.

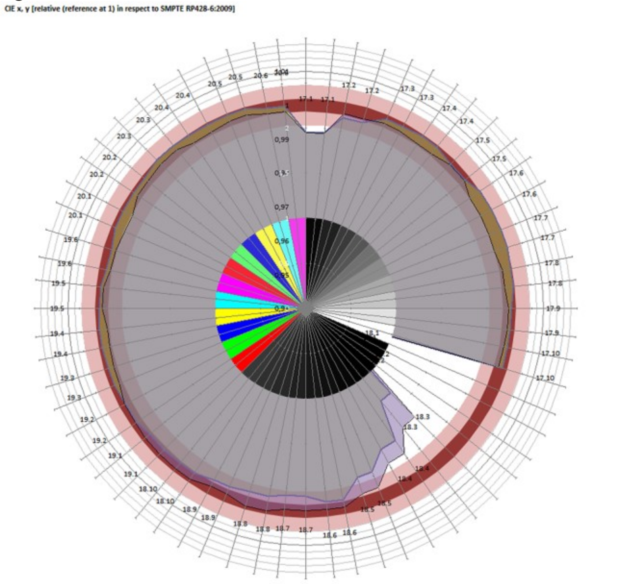

Figure 16. *Relative chromatic deviation (x coordinate in violet, y in green) as difference from the reference at 1 of the test images nr. 17, 18, 19 and 20 as projected by the D-Cinema projector Christie CP-4420*

It shows that the special adjustments in optical part together with the projector calibration by a reference device as well as measuring standard set of test images and their graphical evaluation might significantly improve the image quality of the projector from which we would not expect.

This projector with above mentioned special setup meets at the dedicated space the criteria for review rooms. Besides five lowest luminance black-to-dark steps and one darkest black-to-white step which both shift as usual to blue tones. So the question remains how much and whether it really matter for viewer's perception at the commercial cinema or very critical observation at the review room? That is why we adopted the new CIEDE2000 color difference formula tool for more objective and pragmatic assessment to better understand the importance of the color and tonality error in the specific cinema low light levels. We consider CIEDE2000 formula as suitable perceptual uniform assessment tool considering above mentioned discussion about the importance of mesopic vision at regular screening conditions.

The overall value ΔE*00 as an objective measure of color difference CIEDE2000 between measured chromatic deviation from the reference with an adaptation to the DCI-P3 white point can be transformed into five categories that indicate the subjective perception of the difference. The approximate boundaries of ΔE*00 based on published [2] and experimentally validated results [8] to assess subjectively observed difference for each category are listed in Table 1.

Evaluation scale of subjectively perceived color differences

Category	Perceived difference	ΔE^*_{00}
1	Imperceptible	ΔE*00 < 0.5
2	Almost imperceptible	0.5 ≤ ΔE*00 < 3.7
3	Perceptible	3.7 ≤ ΔE*00 < 6.8
4	Significant	6.8 ≤ ΔE*00 < 12.6
5	Large	12.6 ≤ ΔE*00

We expect for the image projector quality by means of objective measurement SMPTE tolerance [3, 4] and in the context of the practical subjective assessment of perceived differences, the most annoying are such gray steps with luminance above half to one cd/m^2 that have not fine tonal gradation and are not color-neutral. The measured results of all the D-Cinema projectors, intended not only for screening at the commercial theaters but also at the review rooms where critical assessment is very important, were not satisfactory and such the devices do not fully comply with mentioned SMPTE standards and DCI specification ver. 1.3. CIEDE 2000 formula allows evaluating partially unsatisfactory measured results compared to SMPTE standards in a new light as visible in the last figure.

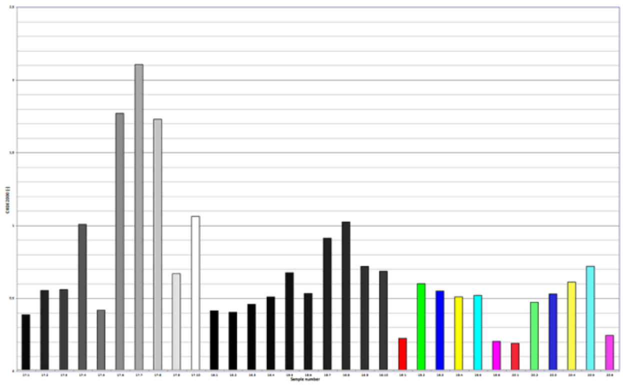

Figure 17. *Perceived color differences of the test images nr. 17, 18, 19 and 20 from the reference expressed by the CIEDE2000 formula as projected by the D-Cinema projector Christie CP-4420*

As we can see from last figure above, our CIEDE2000 calculation of the best Digital Cinema Environment we have tested are not far away from the SMPTE engineering guideline [2] recommendation. That means our finding about five lowest luminance black-to-dark steps and one darkest black-to-white step which are out of colorimetric tolerance does not matter too much.

Following the results, for our future efforts we plan to perform proper subjective image quality assessment experiment with a group of observers. Also, we plan to exploit measured data evaluation by the CIECAM02 color appearance model that might better reflect color perception under mesopic illuminaton. Moreover, we plan to compare different photometer and spectrophotometer accuracy and repeatability or various DCP as DCDM players using creative white points (D65, D60, D55 etc.) different from the reference white point (DCI-P3) defined by the Standards [3] in the near future.

Conclusions

We can conclude that different presentation technologies for D-Cinema projectors and displays, including such state-of-art dedicated devices for postproduction studios or new technologies as phosphor-laser projectors have their strengths and weaknesses.

Thus, we have developed new image quality tools to graphically evaluate measured luminance and chrominance coordinates of the test DCP projected on the screen by the D-Cinema projector in the MS Excel environment, based on DCI specification and international SMPTE and ISO standard, not only for objective analysis but also for an assessment of perceived differences using CIEDE2000 formula. Moreover, we developed simpler, faster and more precise measurement from the cinema screen by the innovation of the engineering

SMPTE guidelines and creation of thirty two full-field test images as explained above.

A set of methodologies and tools for Digital Cinema Environment display were developed, implemented and verified. Measurement of the Czech and Slovak commercial cinema and review rooms were discussed. We believe these engineering guideline innovations and visual quality interpretation tools with the results of our iteration experiments may reduce the costs and improve quality control for both digital born or digitized archival films projection not only for public theatre owners but also for government bodies which financially support cinema digitization or else for different heritage institutions with regards to acquisition and maintenance of their review screening rooms.

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