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Color analysis and color management in mass digitization of transparencies at the National Digital Archives in Poland.

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Abstract

Professional digitization of cultural heritage items in the Polish State Archives can be divided into two major branches: digital imaging of transparencies and reflectives. While the latter has been meticulously standardized in accordance with ISO 19264 and domestic guidelines, the case is much different for the former. This paper is aimed at addressing the issue of color in mass digitization projects.

Overview of digitization of transparencies at the NDA

At the National Digital Archives (NDA) transparencies account for no less than 90% of the entire archival photographic collection, comprised of more than 16 million images. These photos are being digitized in a mass process at a rate of up to 60,000 objects annualy, however due to the lack of eligible reference targets and the absence of ΔE quality assurance software the NDA has had to work its way around these limitations. The workflow the NDA initiated involves color analysis prior to imaging and focuses on the assessment of color in illumination and lighting as well as color rendering by digital camera sensor and lens based on color inspection of 16-bit RAW image of a transparent IT8.7 target with Capture One Pro 23.

Color analysis and color management workflow for transparencies at the NDA

The NDA has formulated a simple quality assurance method built off color analysis tools as well as calibration and profiling procedure with basICColor input 6 profiling software coupled with both IT8.7 transparent profiling chart and 35 mm Standard Format Film target which is used for White Balance adjustment with Capture One Pro software due to its neutral grey area. This method works best with greyscale imagery yet has proven quite useful with color photography as well. The scope of color analysis at the NDA involves a number of expanded color properties like CRI, SSI, TLCI/TLMF, CCT, TM-30-18, the electromagnetic spectrum of artificial light source and color fidelity by hue angle bin to name a few, making sure the light itself meets the NDA's quality expectations, but the color analysis at the NDA goes even further especially when it comes to transparent negative color film collections.

The hardware

In view of the author color analysis and color management begin with hardware. At the National Digital Archives digital imaging of both transparencies and reflectives is done with two PHASE ONE XF camera systems. These systems comprise of two PHASE ONE XF camera bodies: one paired with standard (not Trichromatic) PHASE ONE IQ3 100 MP digital back and second with PHASE ONE IQ4 150 MP digital back. Both cameras come with Schneider-KREUZNACH LS 120 mm 1:4 MACRO *Blue Ring* lenses with one additional Schenider-KREUZNACH LS 80 mm 1:2.8 *Blue Ring* Mark II lens for larger reflectives. These macro lenses have already became an international standard of digitization of transparencies.

Along with abovementioned cameras come set of *must-have* accessories:

1. Two EIZO ColorEdge CG279X and two EIZO ColorEdge CG2700S color management monitors;
2. One KAISER FOTOTECHNIK re*PRO* RSP 1.5 copystand system;
3. One AC&C Negative Scanner system;
4. Two Manfrotto 405 geared heads;
5. One KAISER FOTOTECHNIK prolite LED 37/25 professional digitization light box;
6. Two AKURAT D18 LED panels for digitization of reflective materials;
7. Two Manfrotto 1004BAC tripods;
8. Two professional spectrophotometers: i1Photo Pro 2 and *SEKONIC* C-800 SPECTROMASTER;
9. Reference targets: ISA *Golden Thread* Device-Level-Target and Object-Level-Target (flexible and rigid), Coloraid IT8.7 transparent targets on Kodachrome and FUJICHROME photosensitive emulsion, ISA Spatial Frequency Response SE1, Munsell COLOR Linear Grayscale, ISA Standard Format Film Target (35 mm), USAF-1951, x-rite ColorChecker Classic and Digital ColorChecker SG.

Figure 1*. Main digital imaging lab at the NDA.*

The software

Paired with aforementioned equipment is the software which serves two purposes: camera calibration and profiling as well as image quality assurance. The NDA has chosen basICColor input 6 camera calibration and profiling software for a main tool delivering precise ICC profiles. Prior to basICColor input 6 software the NDA used x-rite i1 Profiler which is compatible with the same IT8.7 transparent targets yet does not generate ICC profiles of corresponding color accuracy. Digital camera systems are calibrated and profiled with 35 mm Coloraid.de IT8.7 transparent targets, primarily on Kodachrome but also FUJICHROME emulsion.

Another highly relevant software is BabelColor Color Translator & Analyzer 6 software which the NDA has implemented for the sole purpose of continuous lighting inspection and monitoring especially its spectral characteristics like CRI, color stability and MI (Metamerism Index) which determine color rendering and registration. This software tool is compatible with i1Photo Pro 2 spectrophotometer but also used interchangeably with *SEKONIC* C-800 SPECTROMASTER spectrophotometer, both complimenting each other in terms of parameters measured.

Hardware assessment

Digitization of transparencies, much like digitization in general, is all about the quality of light and color management. One major difference pertaining to digitization of transparencies is the multitude of photosensitive emulsions. Among these different kinds of emulsions only major film manufacturers the likes of Kodak, FUJI and *agfa* are represented in transparent IT8.7 target range. On the other hand less popular in the West yet very common in the East film stocks, particularly from the former Eastern Bloc, i.e. ORWO or Svema have not seen their calibration and profiling targets at least for now and images taken with these films count in hundreds of thousands if not millions. The same applies to very prominent CineStill stock. The only way to go around this limitation is to ensure proper quality of light transmitted through the film base and this is exactly the first step towards color analysis and color management in the framework of transparency digital imaging.

The NDA has implemented a professional grade KAISER prolite LED 37/25 lightbox to the digitization of transparencies. The lightbox itself, according to the manufacturer has the brightness of 9 400 cd/m^2, color temperature ca. 6000K and CRI of 90. These characteristics are enough when it comes to digital imaging of transparencies yet are they true and do they suffice? The light emitted by this lightbox is first analyzed with *SEKONIC* C-800 SPECTROMASTER spectrophotometer for a number of parameters including spectral characteristics, Color Rendering Index (CRI) as well as Correlated Color Temperature (CCT) among other things.

***Figure 2**. Lightbox analysis with SEKONIC C-800.*

The readout includes a set of basic and advanced parameters including among other things light spectrum, light intensity in a specific area around the lightbox in luxes, Color Rendering Index, TMI-30 measurement and Δuv which shows how the color of a light source changes at different angles. These parameters coupled together form a broader insight into the light characteristics. They also monitor how the color of light changes with time but also along with the distance between the light source and measuring device. One big advantage of such spectrophotometer is the ability to customize the parameters which will be displayed at the readout.

The device indicates Color Rendering Index of 92 which is correct for a professional digital imaging light source. The device also shown Correlated Color Temperature of 6098K, 6170K and 6212K respectively. This might be a token of light source's color fluctuation or stem from another reason. Whatever the cause may be there is no digitization standard which would specify the tolerance of light source's color temperature fluctuation. It is then highly advised to repeat the measurement at regular time intervals and adjust white balance accordingly.

SEKONIC C-800 spectrophotometer also provides an even more detail look into light's characteristics with its in-depth reports generated with *SEKONIC* C-800 Utility software. These reports

Initial measurement can be further corroborated with auxiliary illumination analysis using BabelColor Color Translator & Analyzer 6 software combined with i1Photo Pro 2 spectrophotometer.

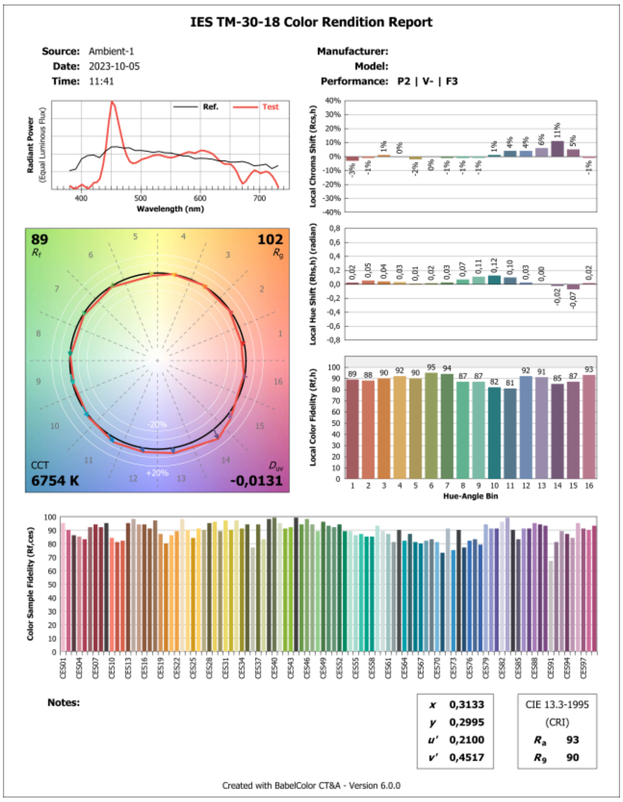

***Figure 3**. Lightbox analysis with CT&A 6 and i1Photo Pro 2.*

The analysis with abovementioned software relies on ANSI/IES TM-30 standard which covers specifically solid state light sources and offers a broad glimpse into the light characteristics not reported by the *SEKONIC* spectrophotometer including detail look into i.e. Local Color Fidelity vs. Hue-Angle Bin, Local Hue Shift and Local Chroma Shift but most importantly Color Sample Fidelity comprised of 99 distinguished colors [1]. There are no digitization guidelines capturing these parameters to the author's knowledge, yet the deeper the insight the better an overview of a light source's properties and how a particular light source performs against its competitors.

Seeing from the results of CT&A's Color Rendition Report the light emitted by the lightbox sways towards cold purple color which at imaging has to be compensated for with neutral grey white balance calibration with Capture One Pro. The first graph on the report also indicates a huge spike between 440 nm and 480 nm in the light's spectrum preceded by a drop in blues between 390 and 430 nm.

The lightbox offers ca. 85% illuminance uniformity which means that prior to imaging an LCC profile has to be created in order to achieve even illumination across the entire frame and by extension even color capture.

Upon light analysis comes the photography system. Camera setup which is currently in use at the NDA and has been subject to analysis for the sake of this paper is comprised of the following elements: PHASE ONE XF digital camera body with a prism viewfinder, PHASE ONE IQ3 100 MP standard digital back, Schneider-KREUZNACH LS 120 mm 1:4 MACRO *Blue Ring* prime lens. The camera is mounted to KAISER re*PRO* RSP 1.5 copystand with Manfrotto 405 geared head ensuring its proper upfront position in a quick and intuitive way.

Each photosensitive sensor has its own distinct spectral sensitivity characteristics which show how said sensor reacts to light at each wavelength of a visible spectrum. This is considered an essential parameter when it comes to color analysis in the field of optics. The NDA does not have the tools such as Monochromator or appliances the likes of camSPECS by ImageEngineering.de to measure spectral sensitivity of a standard PHASE ONE IQ3 100 MP digital back on our own yet it is important to note that color analysis of a camera sensor begins right here. A comprehensive article revolving around i.e. spectral sensitivity of a standard and trichromatic IQ3 100 MP digital back can be found here [2].

Seen from the spectral sensitivity graph the digital back has a green dominant combined with certain loss of reds which is a result of a standard Bayer color filter array for arranging RGB color filters. That way spectral sensitivity helps in assessing camera sensor's color gamut. Sensor's spectral sensitivity is closely connected to electromagnetic spectrum of an artificial light source. The more spectral sensitivity aligns with the electromagnetic spectrum of a light source the better the color accuracy but also the better the spectral sensitivity of a particular sensor the better, more accurate and precise color capture. This is exactly the reason behind purchasing high-end digital camera systems for digital imaging bearing the widest tonal range and detail density.

Another way to measure and monitor sensor's performance is the analysis of a Standard Format Film Target with a free, designated software – the MSScan. Both the software and the target do not measure any color accuracy parameters, only the resolution, dynamic range, sharpness which contribute to the way color is captured. The requirements the sensor has to meet are based on FADGI 4-star quality level as well as the NDA's own experience and quality expectations:

1. Resolution no less than 4000 PPI, preferably 5000 PPI or 5000 px on shorter edge of an image. The resolution of up to 5000 px applies particularly to 135 film, hence the introduction of 150 MP sensor at the NDA. Both sensor size and pixel density affect color capture in a way that larger sensors with higher optical resolutions provide for higher dynamic range thus increasing the total number of colors but more importantly soft transitions from one color to another that can be registered;
2. MTF-10 no less than 0.46 cy/px at Sampling efficiency no less than 90%;
3. MTF-50 no less than 0.30 cy/px at Sampling efficiency no less than 90%.

Lens sharpness is another issue which comes into play regarding color registration. This detail is sometimes overlooked. The operator has to make sure that the light entering the lens is not separated into its different wavelengths creating an outline around contrasting objects. If the lens is misfocused by even a small margin one may observe artifacts bearing close resemblance to those of chromatic aberration. This is particularly important in case of manual focusing yet every now and then even autofocus misses its focal plane and it is shown when zooming an image above 100%. Figure 5 highlights the difference between image out of focus (left) and in focus (right). Apart from blur accompanied by the loss of contrast the grid turned up purple or purple red instead of black as shown to the right. Although images appear seemingly sharp when adjusted to the screen size they are in fact distorted when zoomed at 100%. It is important to note that digital imaging of transparencies, especially 120 and 135 film is done at close distance between the sensor and the object, almost on the verge of hyperfocal length where depth of field is shallow, falling somewhere around 1 mm.

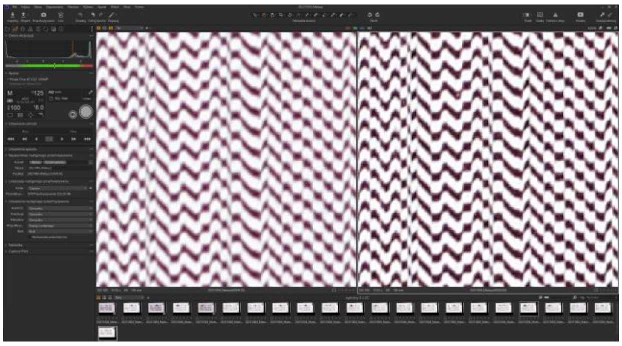

***Figure 4**. Misfocusing artifacts and color distortion.*

Focusing should be done only with a reference target or any other chart including black and white lines, for example a PPI reference chart like USAF-1951. If the lens is out of focus yet a person adjusting the lens cannot see the loss of sharpness stemming from improper focusing then the loss of sharpness may only be detected on the image of the chart. The NDA observed that if the lens moves too near the chart then red outlines appear around black lines whereas when the lens moves too far from the chart blue outlines start to appear. Focusing is much easier with *focus peaking* feature yet the digital back subject to this analysis does not have it therefore such focusing charts provide a useful assistance.

Exposure settings

Upon hardware assessment and prior to camera calibration and profiling proper exposure settings have to be established. These settings heavily impact the registration of color as any kind of underexposure or overexposure would distort colors and turn an image into a flawed misinterpretation instead of accurate reproduction of the original negative or slide. The NDA has established the following exposure triangle:

1. ISO: 100 which is native to the PHASE ONE IQ4 and IQ3 sensors and remains fixed at all times to avoid unnecessary noise distorting and obscuring colors. Native ISO means the amount of electric current passing through the sensor is optimal, it's neither too big causing too much noise nor too low resulting with other kinds of image distortion. It is important to note that the amount of electric current passing through the sensor affects its spectral sensitivity therefore its gamut. In other words, native ISO means the most optimal spectral sensitivity of the sensor. The way the NDA determines the accuracy of ISO is by measuring Standard Deviation however it can only be done with a reflective target like ISA Device-Level-Target or ImageEngineering Universal-Test-Target whereas there is no transparent equivalent of such charts.
2. Aperture value: *f*=8 for 120 film and *f*=11 for 135 film, however it should be noted that the aperture value does not only stem from the depth of field calculation. Depth of field is very shallow for the abovementioned material but proper aperture value also depends on lightbox energy determining shutter speeds an operator has to shoot at. The aperture value is often disputed as some digitizers prefer shooting at *f*=8 while others opt for *f*=11 or even *f*=13. The *f*-stop does not impact color directly, however it may affect color indirectly in a way that the smaller the *f*-stop the more intense light is needed to stay within fast shutter speed range preventing any vibration from distorting the image. If a photographer works with continuous light as it is the case with most of lightboxes then higher *f*-stops are compensated with higher ISOs in order to stay within $^{1}/_{50}{}^{th}$ to $^{1}/_{80}{}^{th}$ of a second shutter speed range and as said before higher ISO affects spectral sensitivity of the sensor and by extension color registration. On the other hand past *f*=16 threshold light diffraction is observed resulting with color misregistration.
3. Shutter speeds ranging from $^{1}/_{10}{}^{th}$ of a second to $^{1}/_{80}{}^{th}$ of a second. The slowest shutter speed pertains to severely overexposed transparencies while the fastest applies to highly underexposed ones. The trick with exposure when it comes to transparencies is that there is no fixed shutter speed that would allow for the same camera calibration and profiling as is the case with reflective material. Digitizing specialists do calibrate and profile their PHASE ONEs with basICColor input 6 pro software and IT8.7 transparent target yet we only do that at one exposure setting we consider the most optimal for the sensor which is for example ISO 100, *f*=8 and $^{1}/_{125}{}^{th}$ of a second shutter speed for analog medium format transparencies. Sometimes all frames from a particular negative or positive film are shot at the same shutter speed but even more often at least three to six frames out of twelve 60x60 mm images on a medium format film are digitized with different shutter speeds resulting with different gradients, hues, highlights and shadows.
4. Metering: Matrix which ensures an even exposure in both highlights and shadows area relatively across the entire frame with bigger emphasis put on the focal point.
5. Curve: Linear or Linear Scientific. There is an ongoing debate which curve provides for better color accuracy as there is no standard specifying this issue. It is alleged that Linear Scientific curve offers more authentic, neutral and less saturated images but in case of transparencies both allow for taking precise reproductions. To assess which curves preset is better a test with basICColor input 6 pro and IT8.7 profiling target would suffice. It only takes shooting said target with linear and then linear scientific curve along with the ICC profile created with the software and then measuring mean ΔE2000 for either of those images.
6. White balance is calibrated manually based on neutral gray field of ISA Standard Format Film Target. Figure 6 shows how this one simple move helps in removing the purple/red tint on the image caused by light characteristics of the light source.
7. Initial RAW images are captured with 16-bit RGB color depth. Upon imaging RAW files are cropped rotated to a readable position and exported to TIFF files with AdobeRGB1998 color space for color images and GrayGamma 2.2. for grayscale images. Occasionally RAW images are edited in terms of tweaking highlights and shadows, but for the most part photography digitization specialists strive for achieving good exposures solely with the use of the equipment instead of software.

Figure. 5*. White Balance calibration with SFF target.*

Exposure settings greatly contribute to the way color is captured yet these settings are interconnected with the choice of lighting, lens characteristics, sensor quality and properties. The lighting itself plays a significant role, because the stronger the transmitted light the greater the range of available shutter speeds. As a result it is easier to adjust the shutter speed to a particular frame, especially either overexposed or underexposed making the most of whatever color has been captured by initial author. On the other hand stronger transmitted light provides the ability to capture images at shorter shutter speeds of up to $^{1}/_{125}{}^{th}$ of a second without getting into either low aperture values or higher ISO which is very convenient because of lower risk of motion blur caused by all sorts of microvibrations in the immediate camera surrounding.

Camera calibration and profiling

Hardware calibration and profiling is often associated with the creation of ICC profile which is supposed to solve all issues revolving around color registration. However, creating an ICC profile has to be preceded by certain steps ensuring that the profile actually works. In fact the creation of ICC profile is the final stage of the process strongly determined by steps taken beforehand.

The process begins with the creation of LCC profile using Capture One Pro software. The LCC compensates for uneven distribution of light across the lightbox providing for equal color registration across the frame. The next step is white calibration or setting up the temperature of light reaching the sensor. This step is absolutely crucial for color capture as the colors will not lean towards either too warm or too cold tints. In order to achieve a neutral white balance the NDA is using Standard Format Film target with neutral grey area across the entire chart.

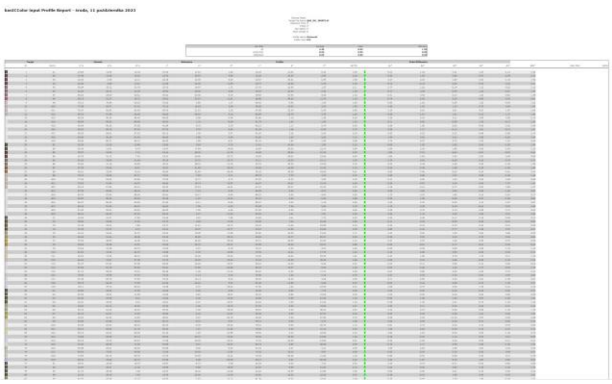

***Figure 6**. Camera profiling with basICColor input 6 pro.*

The choice of basICColor input 6 pro for the NDA's default profiling software stems from the ability to control the quality of camera profiling with a transparent target as the software allows for ΔE measurement prior and after profiling. However, simply measuring ΔE for each color patch of said target at a particular exposure setting only offers an information that the hardware itself is capable of desired color rendering. It will not tell us if the colors are correct when we digitize different frames at different shutter speeds.

Figure 6 shows a comprehensive and extended reported generated with basICColor input 6 pro software. The report is focused on color rendition by the camera turning the camera into a color measuring device. That way the operator gains a color readout from the sensor measured with RGB percentage and L*a*b* color model. Colorimetric values derived from the ICC profile are compared with referential colorimetric values for every individual color patch. This feature is particularly useful because it lets the operator check which colors account for worst Δab measurement thus are most difficult for the camera to cope with.

Digitization of B&W transparencies

Digitization of monochromatic transparencies only seems easier than that of color. Those who shot black and white film stocks know that monochromatic photography is all about light since no color film stock speaks so much about the light as black and white does. Color photography turns viewer's attention away from the light and towards colors whereas monochromatic photography brings light to the surface while color gives way to tonality.

It is an open question, given available technology, should monochromatic negatives be digitized with either standard sensors or their achromatic counterparts. However, to ensure proper tonality retention with whatever means the NDA has in its disposal, digitizers do two things. First, white calibration with neutral grey patch on the ISA Standard Format Film Target and second, using basICColor input 6 pro a custom target is created based on the aforementioned Standard Format Film Target with measured values of white, grey and black patches. The same procedure can be replicated with a Munsell Linear Grayscale chart for black and white reflectives. This custom target serves as a source of ICC profile. Upon creating an ICC profile digitizers then proceed to calibration and profiling control with same software. Usually mean ΔE2000 stays somewhere between 2 and 3 which is acceptable.

This quick procedure does not guarantee the same mean ΔE2000 for every frame because frames are scanned with different shutter speeds corresponding to the degree of exposure of the original source. Combined with illumination quality check this simple procedure only reassures an operator that the hardware and the software are capable of achieving precise tonal reproduction.

All monochromatic transparencies are photographed with different shutter speeds, usually ranging from ${}^{1}/_{10}{}^{\text{th}}$ to ${}^{1}/_{80}{}^{\text{th}}$ of a second. All other exposure settings including aperture value, ISO sensitivity, white balance and curves present remain fixed at all times. Images are captured as 16-bit RGB RAW files which upon cropping are exported to 16-bit TIFF GrayGamma 2.2 files.

Digitization of color transparencies

Digitization of color transparencies is no less complicated than that of monochromes, it may only be more nuanced. Just like different black and white photosensitive emulsions determine different tonalities of greyscale images the same applies to color negatives and slides, for example Kodak emulsion leans towards yellow warm colors, FUJI has a colder, green tint and *agfa* emulsion falls somewhere in the middle between the former two. Digital imaging should follow these characteristics. It is for this reason that camera calibration and profiling is done with a reference target matching the specifics of original emulsions, for example prior to digital imaging of FUJICHROME color transparency positives the camera is calibrated with a Coloraid.de IT8.7 target on FUJICHROME emulsions. Color transparency negatives on Kodak emulsion call for camera calibration and profiling with a Kodachrome IT8.7 target. No matter which target is used at camera profiling stage with basiCColor input 6 pro software, mean ΔE2000 usually falls somewhere below 3 which is a completely acceptable result. The difference lies in a way images are captured. The same image captured with ICC profile build off FUJICHROME reference values will differ in terms of color and tonality from the one taken with ICC profile based on Kodachrome reference values [3]. This is also why niche films, particularly Soviet era film stocks pose such a problem with colors and tonality because there are no targets and no references values measured for said photosensitive emulsions. In case of stocks from former Eastern Bloc the NDA focuses on retrieving natural and neutral colors of color transparencies as well as building user presets more less matching the properties of said film stocks based on our own experience with digitizing them.

Color analysis and color management procedure is nearly identical to that of greyscale imaging. The only thing different is the white balance calibration for color transparency negatives. Initially white balance is calibrated according to

Standard Format Fim Target neutral grey area prior to camera profiling with basICColor input 6 pro software but at imaging white balance is picked again from empty space between frames of the original negative. That way the initial blue mask of the negative is easily removed and the image becomes clearer as well as more natural.

Editing color transparencies divides into two workflows which are color transparency negatives and color transparency positives. For color transparent positives white balance is calibrated with Standard Format Film target and remains fixed at all times.. Such imagery is simply cropped and exported to 16-bit AdobeRGB1998 TIFF files. The workflow turns more complexed with color transparency negatives. Apart from aforementioned white balance switch digitizers create different style presets with Capture One Pro for specific kinds of photosensitive emulsions. These style presets include adjustments to white balance and color balance, ICC profile, levels and target levels for nearly all emulsions identified in the NDA's photography collections. These user styles are applied at editing to match the color captured with the camera to the properties of the original documentation. As a result editing can be done in an automated manner yet remain strictly under our control. Upon editing images are exported to 16-bit AdobeRGB1998 TIFF files.

Conclusion

By author's own experience still a lot of work has to be done regarding the awareness of color science significance in the archival digitization pipeline. In most cases the archives are consumers of color science technologies simply working with what they have. It is the responsibility of the NDA to keep up with newest advancements to color science and color imaging technologies as well as support initiatives aimed at raising the bar of digital imaging quality.

Currently the lack of international or domestic standards remains the biggest issue with digitizing transparent stock. The author believes such standards or guidelines should probably revolve around recommendations for hardware capabilities, specific parameters for lighting and illumination as well as creation of new reference targets for automated quality assurance. Color analysis at the NDA has been focused primarily on measurement of light characteristics and sensor capability assessment. It begins with hardware check and involves the following parameters: Color Rendering Index (CRI), Correlated Color Temperature (CCT), Color Fidelity Index (TM-30), Spectral Similarity Index (SSI) etc. The biggest challenge ahead is how to optimize color analysis procedure for mass digitization of transparencies. Most digitizers do not delve into technicalities like TM-30 standard or white calibration with reference targets like the Standard Format Film target. It is likely only fewer people recognize spectral sensitivity issue let alone have the means to measure it.

Perhaps technical guidelines for digital imaging of transparencies should include specific recommendations on how to handle particular equipment, mostly digital cameras and their derivatives since only fewer photography scanners are still available on the market. Such guidelines should spread awareness of color science that goes into digital imaging and quality assurance. They should also encourage digitizers to define primary objectives of digitization – be it long-term preservation or quick and easy access online. These objectives are not contradictory, they compliment each other and creating high-definition digital content does not render it too difficult to process for availability on the internet.

The NDA is yet to answer questions about color analysis applications to mass digitization, particularly to what extent should color science be implemented to mass digital imaging process so that every digitizer can handle it? How should the archives be reviewed? Do sharp and clear imagery suffice or should it be subject to more in-depth color analysis? Our current workflow does not provide answers to abovementioned issues yet it is the best thing we have come up with in current circumstances. A new window opens for mass digitization of transparencies in Poland. A set of Polish technical guidelines for flat art digitization is currently discussed and transparencies may play a significant role but it is a topic for a whole other presentation.

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