Set of Methodologies for Archive Film Digitization and Restoration with Examples of Their Application in ORWO Region

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Abstract

In this paper, we present a set of verified methodologies suitable for application to a particular problem of archive films' restoration and digitization, especially when a nonstandard laboratory or creative techniques were used, which is typical for so-called ORWO region. The umbrella of the presented techniques is formed by established Digitally Restored Authorizate (DRA) methodology, with its aim to achieve the appearance of the audio and visual components of the digitized film as close as possible to the original author's concept. Among the methodologies, we present tools for objective assessment of perceived differences in the outcomes of the color grading process. These techniques are suitable for evaluation of appearance match among various available versions of the digitized film in respect to the DRA outcome.

Introduction

One of the main provisions of the outcome of the digitization and digital restoration process is that the appearance of the digitized film is as close as possible to the author's original concept as presented at the time of the film origin (e.g. production approval screening or first run). To achieve the above-stated goal is not easy even if a widely standardized and well-documented laboratory and creative process were used for the film production. Moreover, it is nearly impossible to fulfill the requirements without specifically designed and verified methodologies if the process is neither standardized nor well technically documented. The motivation for the presented work comes especially from the need to establish methodologies and proper technical procedures to achieve high-quality digitization and restoration of the films produced in the very particular ORWO region. The ORWO region comes from the name of the ORiginal WOlfen movie stock manufacturer located in Wolfen near Leipzig, former German Democratic Republic. Originally Agfa in Wolfen produced the first tripack negative – positive film stock from 1936. Know-how and chemical patents were exploited by US Army in April 1945. The year later Soviet administration took over the factory and transferred major technology with German experts to Shostka in Ukraine. Film stock production in Wolfen was reestablished at the end of 1953, but the quality has been declined until 1964 when the East Germany brand Agfa was changed to ORWO after the trial with West Germany producer Agfa in Leverkusen which merged with Belgium Gevaert film stock producer in the same year. ORWO region comprises countries and their film archives in Central and Eastern Europe (e.g. Czech Republic, Slovakia, Poland, Hungary, Romania, Bulgaria, seven states of the former Yugoslavia and Baltic countries, etc.). In this region, cinematographers were used to shot color films on standard Eastmancolor original camera negative (OCN) but all positives and some intermediate were printed on ORWO positive film stock.

In the following sections the problem is at first described, the Digitally Restored Authorizate (DRA) concept is briefly reviewed, then the tools for objective assessment of perceived differences in the outcome of color grading process are presented.

The results presented in this paper were obtained within the research project NAKI No. DF13P01OVV006 "Methodics of digitizing of the national film fund"[1] of the Ministry of Culture of the Czech Republic, which is performed at the Film and TV School (FAMU) of Academy of Performing Arts in Prague[2].

Problem description

In the past, mainly throughout the years 1953 to 1998, the laboratory and creative techniques applied in film production in ORWO region were very specific. The cinematographers had to shoot their movies using Eastmancolor OCN but present them on low-cost variable quality ORWO positive film stock. The other significant difference, in comparison to standards common in Northern America or major western European countries at the time, was that the release prints (RP) for distribution were printed directly using OCN and not from the intermediate (IM) films. Straightforward Eastmancolor OCN to Eastmancolor RP process was discarded due to high-cost of Eastmancolor RP film stock in mentioned region but besides Hungary where availability of Eastmancolor prints for cinema release was common from the late 1970s. ORWO OCN to ORWO RP was fortunately also discarded in the region mainly in Cinemascope format (aspect ratio 1:2.55 or 1:2.35) because of fuzzy and low-resolution of ORWO OCN film stock. However, there are feature films in Academy format (aspect ratio 1:1.37) shot on Agfacolor OCN, e.g. Czechoslovakian "Silver Wind" (1954) directed by Václav Krška and photographed by Ferdinand Pečenka.

To give an example, there is a distinct look of Agfa and ORWO visible in color film prints made in different years 1956, 1976 and 2001 from the same OCN Agfacolor B on fairly different versions of film stock Agfacolor PC7, Orwocolor PC7 and Agfa-Gevaert color CP10 produced in Wolfen and Leverkusen factory as can be seen in Figure 1. Original Agfacolor prints in the 1950s have limited color range, slightly desaturated colors with brownish green tint where yellow-green hues are fundamentally more saturated than others, and some natural colors as deep

[1] Project website: http://www.research-dra.com/
[2] University website: https://www.famu.cz/eng

Figure 1. Example (Czechoslovak film "Silver Wind" (1954)) comparing Agfa and ORWO color prints made in the years 1956, 1976 and 2001 from the same OCN Agfacolor B. (a) 1956 - Agfacolor PC7 (left). (b) 1976 - Orwocolor PC7 (center). (c) 2001 - Agfa-Gevaert color CP10 (right). CIEDE2000 color difference calculated (CIE xyY coordinates measured with VFX-Consulting SpecTD spectrophotometer & densitometer) for the skin tones of the frame in the upper row: $\Delta E_{00(1956-1976)} = 16.3$, $\Delta E_{00(1956-2001)} = 14.0$, $\Delta E_{00(1976-2001)} = 4.1$.

blue or purple are not reproducible as explained in the original German article from 1951 [9]. These film stock characteristics are very important for special set up of film digitization facilities since the majority of professional film scanners are optimized for OCN Eastmancolor with the orange mask.

This decision of responsible establishment at the time allowed cinematographers in ORWO region to shoot mostly on high-quality Eastmancolor negative film stock. As a result, also the creative techniques were modified. The altered lighting setup, facial makeup, colors of costumes and props had to be used to achieve the required light tonality artistic concept tuned to ORWO RP. The distinct look has to be respected in digitization and restoration in order not to alter the author's original concept. Moreover, the resulting image quality of the RP was further deteriorated by different positive color dye layers order of Eastmancolor and ORWO film stock. This fact led not only to lowered image quality but also to substantial degradation of optical sound quality. An example of selected RP frame from Miloš Forman's first color feature film, "Firemen's Ball" (1967), nominated for the Best Foreign Language Film at the 41st Academy Awards, before and after grading, can be seen in Figure 2. In this case ORWO prints were used for Central and Eastern Europe cinema distribution and Eastmancolor prints were used for theatrical distribution in USA and western Europe in a slightly different censored versions and formats. [7]

The ORWO region comprises numerous countries. Therefore the problem we aim to solve is highly relevant to the considerable amount of film heritage to be digitized and covers at least one-fifth of the population of the European Union with the same or higher number of prospective consumers of the digitized and restored content.

Digitally Restored Authorizate

The methodology of Digitally Restored Authorizate (DRA) defines a procedure and set of tools to achieve the audio and visual appearance of the digitized film as close as possible to the original author's concept. The DRA methodology was introduced in our previous papers [3, 4] and also discussed in local journal paper

Figure 2. Example of specific color characteristics of ORWO and Kodak Eastmancolor release print (RP) before and after grading, using a frame of "The Firemen's Ball", an important piece of Czechoslovak cinematography produced in 1967. (a) RP ORWO scan (upper-left). (b) RP ORWO graded (upper-right). (c) RP Kodak scan (lower-left). (d) RP Kodak graded (lower-right).

[6], here only a brief overview is presented.

The methodology of DRA was developed and its steps were verified during the digitalization and restoration of various Czech movies in the years 2011-2015. These movies are namely "Closely Watched Trains" (1966), "Marketa Lazarová" (1967), "The Firemen's Ball" (1967), "All My Compatriots" (1969), and "The Stone Bridge" (1996).

The approach to solving the above-stated problems as defined by the DRA methodology can be summarized in the following steps. The simplified diagram describing the main idea of the DRA methodology can be seen in Figure 3.

1. A master restorer is assigned, and a group of experts is formed.
2. The film print, denoted as Reference Release Print (RRP), with the appearance closest to the original is selected.
3. Key scenes critical for the film appearance are selected.
4. These samples are scanned from the RRP in suitable resolution.
5. Accurate Digital Facsimile of RRP (DFRRP) is created with the appearance equal to RRP.
6. OCN is scanned in suitable resolution resulting in Digital Source Master (DSM).
7. Color grading of the OCN in selected key scenes led by the master restorer and supported by the group of experts is performed, removing all unwanted color and light tonality drifts resulting in Educated Guess of Answer Print (EGAP).
8. DRA of the whole movie is created based on the EGAP by the digital colorist followed by the fine tuning and approval from the master restorer and the expert group.

The DRA is not a new version of the original work, but it is its original digital source. The importance of the digital restorer is obvious and can be seen in Figure 5. The necessity for a methodology like the DRA is even more evident in the case of ORWO region. Supporting technical methodologies to achieve the results required by the DRA are described in the following subsections.

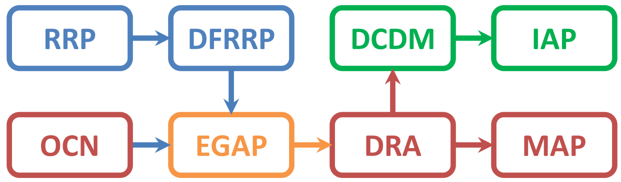

Figure 3. Simplified diagram of DRA methodology. Original sources are in red: Original Camera Negative (OCN), Digitally Restored Authorizate (DRA), Master Archive Package (MAP). Copies are in blue: Reference Release Print (RRP), Digital Facsimile of Reference Release Print (DFRRP). Digital dissemination masters are in green: Digital Cinema Distribution Master (DCDM), Intermediate Access Package (IAP). Orange color denotes the crucial step of restoration based on estimation of the DRA utilizing the Educated Guess of Answer Print (EGAP) [6].

Supporting technical methodologies

There is a need for further supporting methodologies and techniques able to provide quantification of perceived differences among various outcomes of the above-described color grading process. Among the approaches, based on our previous results [3, 4], we proposed, implemented and verified the following technical tools and methodologies supporting DRA creation, work of digital restorer, the group of experts and digital colorist.

- Assessment of perceived differences in color and light tonality appearance based on CIEDE2000 [10] color difference formula applied to various types of evaluated images including measurements in digital image files, the spectrophotometric analysis from the projection screen, and colorimetric measurements based on imaging colorimeter [4].
- Assessment of differences between evaluated image files based on statistical properties of their histograms.

Assessment of perceived differences in color and light tonality appearance

This methodology is intended to be used by the digital restorer as an assisting tool for measuring and monitoring the already digitized image sources displayed using a reference digital projector. The split screen is used, while the DFRRP is displayed on one side and the DRA on the other. If required, it can be also used to assess the differences between the analog film RRP displayed using a film projector and the DFRRP with the digital one. It is also possible to perform a direct evaluation of colorimetric data stored in the compared image files.

Comparison of different versions of key scenes from the viewpoint of color and light tonality can be objectively performed using three different techniques [3, 4]. These procedures differ in the way how the colorimetric characterization is obtained, namely:

1. measuring the color samples of selected key scenes using a colorimeter or spectrophotometer directly from the screen,
2. capturing the projected image from the projection screen using imaging colorimeter or calibrated digital camera (D-SLR),
3. evaluating the colorimetric data directly from image files.

The aim of all of the above techniques is to obtain a reliable colorimetric description of the image projected onto a screen in the color space independent of the device, preferably in the form of CIE XYZ tristimulus values (see Figure 4). The technical details of each technique are discussed in our previous work [3, 4].

The first procedure is straightforward, colorimetric parameters of the selected color samples are measured from the projection screen in specific areas, using a colorimeter or spectrophotometer. The device should meet the appropriate measurement accuracy tolerances for control screening. Using this procedure allows for high accuracy measurement of trichromatic components. The main disadvantage of this procedure is that the number of measurement sites within a test frame is limited.

The second procedure is based on capturing the colorimetric description of the projected image from the projection screen. It can be done preferably employing 2D image colorimeter. Instead of this device, more affordable calibrated professional digital SLR (D-SLR) can be used. The setup provides a 2D distribution of CIE XYZ tristimulus values. Its advantage compared to the first procedure is that it does not limit the number of measuring samples and their selection by an expert is not required. The main disadvantage of this method is lower accuracy in determining the XYZ tristimulus values, especially while using a calibrated digital camera. Colorimetric measurements can be performed under certain conditions using a calibrated digital camera. Digital SLR (D-SLR) camera can replace imaging colorimeter and provide trichromatic components CIE XYZ.

The third procedure is based on direct evaluation of image data and it is not applicable to the analysis of the film image projected using a conventional projector. In the case of DCDM (Digital Cinema Distribution Master) data, the files are available directly in CIE XYZ space. If the goal is to analyze colorimetric and luminance characteristics of the image on the screen in terms of color and light tonality, it is at first necessary to transform the source image data using the colorimetric description of the projection system. The precise characterization of the projection system is not usually available, and if so, the shift in black is often ignored due to parasitic light in a projection room. This method is the simplest of the three as it does not require special equipment (e.g. spectrophotometer, imaging colorimeter) and the projected image does not need to be captured from the screen. Determining CIE XYZ tristimulus values of projected image is based on a simulation. This procedure is therefore not suitable for applications where the aim is to accurately evaluate colorimetric parameters and brightness of the projected image as perceived by the viewer in a particular screening room with unknown colorimetric description. Given the projection systems and rooms should comply with recommendations, the procedure can be used for basic verification of color and light tonality.

The outcome of the three procedures is colorimetric and luminance analysis of image projected onto a screen in the form of tristimulus values CIE XYZ. It characterizes the colorimetric description of the chosen specific sample areas of key scenes or two-dimensional distribution of tristimulus values. In this case, the entire frame of the key scene is analyzed.

Colorimetric CIE XYZ representation is device independent but is not perceptually uniform [1], [2]. Perceptual uniformity is an important property for objective assessment of perceived differences in color and light tonality. The goal is to achieve an ob-

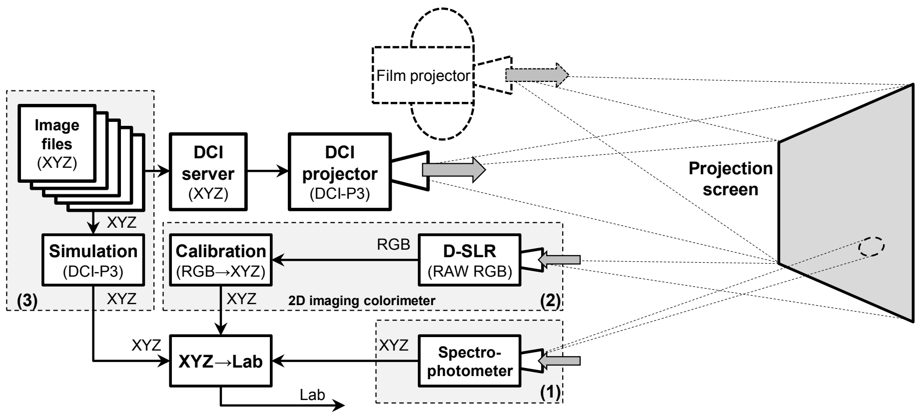

Figure 4. *General principle of the three techniques for derivation of colorimetric screen data in projected cinematographic images. (1) CIE XYZ sample measurement using spectrophotometer. (2) Measurement of 2D distribution of CIE XYZ tristimulus values using 2D imaging colorimeter. (3) CIE XYZ tristimulus values calculation using image data files.*

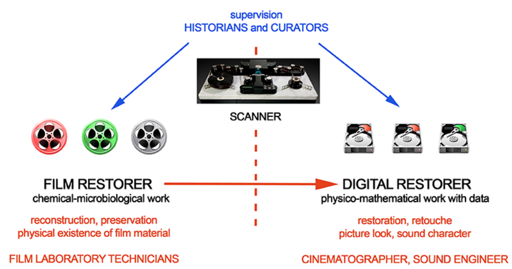

Figure 5. *Task comparison of film and digital restorer and the relationship between professional film and digital restorer of cinematographic works. The responsibility for the look of the archival digitized film and its sound lies on digital restorers educated in a given audio and visual artistic fields. [6].*

jective assessment of the perceived differences between the two projected images of the same content but different color and luminance structure regarding light tonality.

Quantification of perceived differences might be based on the subjective experiment with a group of observers or on objective measurements carried out using image data or colorimetric image parameters measured directly from the screen. The methodology described here focuses on objective quantification of perceived differences. CIEDE2000 [10] color difference formula is a robust method for perceptually uniform evaluation of color differences in homogeneous areas. For comparison of complex color patterns (e.g. images) a spatial extension of the CIE Lab color space, known as S-CIELAB [12], is most commonly used as an input into the CIEDE2000 [11] color difference formula. Based on the literature [10, 11, 12], the verification results for application to the film image [3, 4] and in line with other currently published findings [1], the CIEDE2000 color difference formula is used and the difference is quantified as ΔE_{00}.

The calculation of ΔE_{00} characterizing the color, and light tonality difference between the compared images can be summarized in the following steps. The colorimetric description using CIE XYZ tristimulus values for the two compared images (indicated as x and y) denoted as $XYZ_x(i)_{i=1}^{N}$ and $XYZ_y(i)_{i=1}^{N}$ is converted to the CIE Lab color space, denoted as $Lab_x(i)_{i=1}^{N}$ and

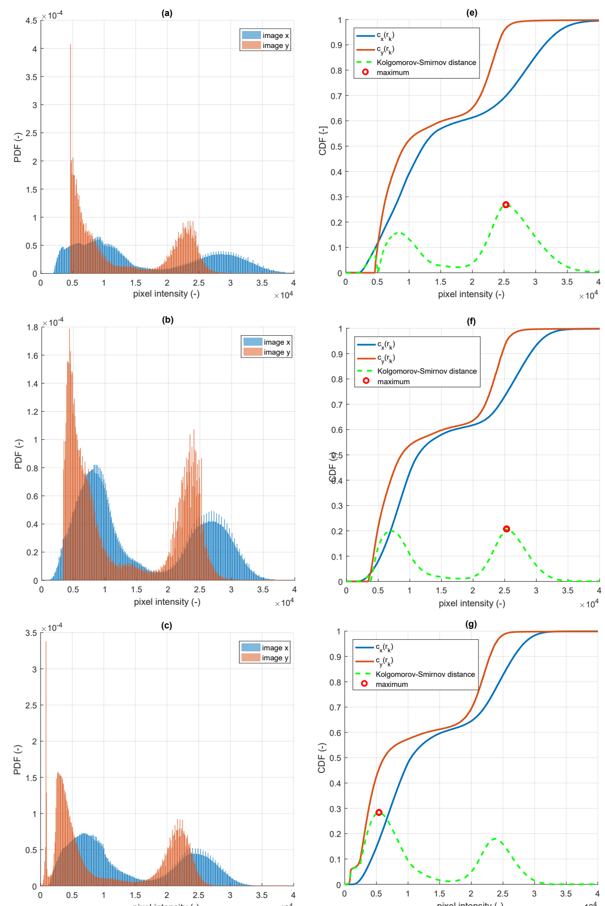

Figure 6. *Histograms of two image files: (a) R color channel, (b) G color channel, (c) B color channel. Cumulative distribution functions of two input images: (e) R color channel, (f) G color channel, (g) B color channel.*

$Lab_y(i)_{i=1}^{N}$. The conversion can be used directly for color samples obtained using a spectrophotometer. For the two-dimensional distribution obtained from imaging colorimeter it is advisable to apply spatial filtering at first. Spatial filtering S-CIELAB can be for simplification replaced by uniform Gaussian filtering. Intensity of filtration (size of a Gaussian convolution kernel σ) is set according to the required sensitivity of the method with respect to a colorimetric comparison of small image planes and delicate patterns. The resulting representation (surface distribution or value for a specific area) in a CIE Lab for two compared images $Lab_x(i)_{i=1}^N$ and $Lab_y(i)_{i=1}^N$ is then used to calculate the CIEDE2000 color difference formula [10]. The value N represents the number of specific color samples obtained from spectrophotometer or the number of pixels for measurements using imaging colorimeter. The value of CIEDE2000 color difference $\Delta E_{00}(i)_{i=1}^N$ is calculated for each pair of color samples. It is recommended to graphically visualize the individual values of $\Delta E_{00}(i)_{i=1}^N$. In the case of data available from imaging colorimeter, it is suitable to display the map of color differences in false colors (see Figure 7). Each selected key scene and in this scene selected frame can be characterized by an average value of color difference $\Delta\bar{E}_{00}$ between compared images. This value is determined as the arithmetic average of $\Delta\bar{E}_{00} = \frac{1}{N}\sum_{i=1}^N \Delta E_{00}(i)$. Weighted average can be also used, where greater weight is given to areas in the image with greater relevance to the overall color and light tonality of the key scenes.

The overall value $\Delta\bar{E}_{00}$ as an objective measure of color difference CIEDE2000 can be transformed into categories that indicate the subjective perception of the difference. This procedure allows for guidance to assess the impact of perceived differences in color and light tonality in two compared images while projected onto a cinematographic screen. The following subjective scale was introduced in our previous work to express subjectively perceived difference. The boundaries of $\Delta\bar{E}_{00}$ based on published and experimentally validated results [3, 4] to assess subjectively observed difference for each category are listed in Table 1.

Evaluation scale of subjectively perceived color differences and experimentally obtained difference measure boundaries.

Category	Perceived difference	$\Delta\bar{E}_{00}$
1	Imperceptible	$\Delta\bar{E}_{00} < 0.5$
2	Almost imperceptible	$0.5 \leq \Delta\bar{E}_{00} < 3.7$
3	Perceptible	$3.7 \leq \Delta\bar{E}_{00} < 6.8$
4	Significant	$6.8 \leq \Delta\bar{E}_{00} < 12.6$
5	Large	$12.6 \leq \Delta\bar{E}_{00}$

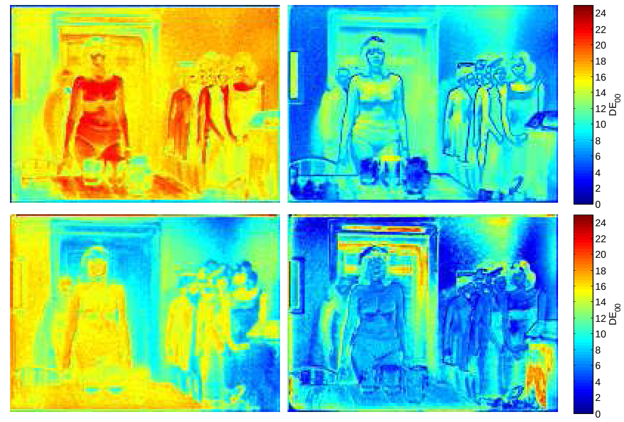

Figure 7. *Example of color differences film prints analysis using ΔE_{00} CIEDE2000 map for the test frames from Figure 2. (a) ORWO scan vs. ORWO graded, $\Delta\bar{E}_{00} = 15.9$ (upper-left). (b) Kodak scan vs. Kodak graded, $\Delta\bar{E}_{00} = 9.0$ (upper-right). (c) ORWO scan vs. Kodak scan, $\Delta\bar{E}_{00} = 12.5$ (lower-left). (d) ORWO graded vs. Kodak graded, $\Delta\bar{E}_{00} = 8.2$ (lower-right).*

Figure 8. *Example of two versions of the test frame to be analyzed before and after grading, taken from film "Capricious Summer", an important piece of Czechoslovak cinematography produced in 1967. (a) Input image x (left). (b) Output image y (right).*

Assessment of differences between evaluated image files based on their statistical properties

This methodology is intended to assess the color structure of images being compared based on the analysis of histograms of image files in different digital formats, especially distribution, i.e. Digital Cinema Package (DCP) and Intermediate Access Package (IAP), or mastering and long term preservation, i.e. Digital Cinema Distribution Master (DCDM), Master Archive Package (MAP). The goal of this technique is to establish a process for simple conformity assessment of color structure in levels of primary image colors R, G, B. It is based on the analysis of DRA's histograms and its digital copies DCP, and archive files DCDM, MAP, IAP. This methodology serves as an assisting tool for digital restorer, who, along with the expert group, creates a DRA.

Let the two images to be compared are labeled as x and y (see Figure 8 (a) and (b)) are described by set of pixels in color channels as

$$R_x(i)_{i=1}^N, G_x(i)_{i=1}^N, B_x(i)_{i=1}^N, \tag{1}$$

and

$$R_y(i)_{i=1}^N, G_y(i)_{i=1}^N, B_y(i)_{i=1}^N. \tag{2}$$

Degree of similarity of two image files may be determined as a correlation of probability functions (histogram) of R, G, and B color channels of both images. The standard histogram of color channel (see Figure 6) can be quite complicated, difficult to describe by any analytical function. Therefore, it is preferable to choose a statistical description using the cumulative distribution function (see Figure 6), which usually takes the form of a smooth monotonically increasing function.

Cumulative distribution function $c(r_k)$ is given by

$$c(r_k) = \sum_{j=1}^{k} p(r_j) = \sum_{j=1}^{k} \frac{n_j}{N} \tag{3}$$

where r_j is $j-th$ level of an image intensity, n_j is number of pixels with intensity r_j and N is total number of pixels.

Robust tool suitable to determine the degree of match between the distribution functions for each color channel is the Kolmogorov-Smirnov distance [2, 8]. This metric, known for its low implementation and computational demands, is given by

$$\Delta_{KS}(x,y) = max_k\left(\left|c_x(r_k) - c_y(r_k)\right|\right), \tag{4}$$

where $c_x(r_k)$ and $c_y(r_k)$ are cumulative distribution functions of R, G, and B color channels.

Kolmogorov-Smirnov distance represents a characteristic determined on the basis of knowledge of statistical description of the compared images. This characteristic can be well used as a guideline for the rapid determination of compliance or non-compliance in the luminance structure of the image files containing the same content.

Conclusions

We have developed, implemented and verified various tools supporting the work of digital film restorer, the group of experts and digital colorist. These tools are meant to be used for objective or subjective assessment of perceived differences between various versions of the movie or outcomes of the restoration process.

Selected methodologies used in the process of digitization and restoration of archive films, especially those produced in ORWO region, are presented in this paper. The methodologies were verified during the digitization and restoration of selected Czech movies. Examples and discussion of the results are shown. By utilizing the described techniques, a high-quality digitization results, maintaining the film author's concept, can be obtained with economic aspects also taken into account. Moreover the three sources for the technical-historical research, i.e. film stock identification and measurements, archival documents interpretation, and oral research, have high importance, especially in highly specific ORWO region.

Acknowledgments

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