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“Less is more”: how understanding the process of motion picture film scanning can make your life easier

Alice Plutino; Department of Media Studies, University of Amsterdam, Amsterdam, The Netherlands

Abstract

Since the advent of the Digital Intermediate (DI) and the Cineon system, motion picture film preservation and restoration practices overcame an enormous change derived from the possibility of digitizing and digitally restoring film materials. Today, film materials are scanned using mostly commercial film scanners, which process the frames into the Academy Color Encoding Specification (ACES) and present proprietary LUTs of negative-to-positive conversions, image enhancement, and color correction.

The processing operated by scanner systems is not always openly available. The various digitization hardware and software can lead to different approaches and workflows in motion picture film preservation and restoration, resulting in inconsistency among archives and laboratories.

This work presents an overview of the main approaches and systems used to digitize and encode motion picture film frames to explain these systems' potentials and limits.

Introduction

During the ’90s, the cinematographic industry faced the advent of digital photographic cameras, and Kodak dealt with Sony's marketing on NTSC digital standards by patenting the Cineon system. The Cineon is a technology used to create Digital Intermediates, which led to the standardization of DPX format and the definition of the first digital color system to manage data encodings from analog to digital [1], [2], [3]. Cineon system has been used for the digital restoration of Disney's *Snow White and the Seven Dwarfs* (1937), for the production of the movie *Pleasantville* (1998), and for one of the first digital color corrections in the film *O Brother, Where Art Thou?* (2000). This system allows digitizing analog film materials and printing them back on film, managing colors and tones. Cineon has revolutionized the cinema industry, allowing the digital manipulation of film frames, leading to new ways of performing color editing and special visual effects.

With Cineon and other innovations, the traditional cinematographic workflow, centered around film negatives, underwent a significant shift with digital technologies, encompassing negative scanning and digital camera acquisition. In the absence of a standardized color management system for the diverse sources originating from various digital motion picture cameras and film, the ACES system was developed [4], [5]. ACES system was initiated in 2004 through collaboration with the leading industry technologists and primarily aims to streamline the complexities of managing numerous file formats, image encoding, metadata transfer, color reproduction, and image exchanges within the contemporary motion picture workflow. These systems are used today to create digital preservation copies or acquisition for restoration processes [6]. More specifically, Cineon system has been followed by the development of the Academy Density Exchange (ADX), which today is used to make an RGB encoding of motion picture color negative film within the Academy's Image Interchange Framework (IIF), thus, into the Academy Color Encoding Specification (ACES) values. So, today, film digitization, even for digital preservation purposes, undergoes processing and encoding which are meant to fit into current movie production systems. Before the advent of Cineon and the analog-to-digital system, cinematographic films were preserved and often restored through the analog film workflow, which consists of materials selection (usually negative films) and the re-print on more stable, safe or unfaded positive films, developed over years of research and practices [7].

As it is possible to understand from this very general and resumed description of the restoration practices (see [8] and [9] for more complete explanations), motion picture film digitization and digital restoration practices are quite recent and are born from an industrial boost and necessity to compete with digital video. This swift and unexpected media change forced many archives to quickly convert their practices from analog to digital, totally relying on the technologies and systems used in motion picture film production (e.g., Cineon). Even if motion picture film production systems present some features compatible with preservation practices, many film scanners and software have not been developed following cultural heritage restoration theories and methodologies. Furthermore, the lack of precise standards and shared restoration methodologies has led to a strong diversification of digitization workflows and restoration practices, which rely primarily on the brands of used instruments and technologies instead of shared knowledge of the film materials [6].

Considering the state-of-the-art in motion picture film digitization and preservation, this work presents an overview of the main digitization and digital encoding systems and discusses the context in which these systems are suitable. In conclusion, some examples where the use of these systems can be avoided will be presented, and a simplification of the digitization process will be discussed.

Digitization systems and technologies

Cinematographic Film Scanners

In recent years, many different approaches to cinematographic materials digitization and restoration have been developed. Considering the FIAF (International Federation of Film Archives) list of film scanners, we can categorize the scanners in: commercial scanners and prototypes [10]. Here, prototypes are divided into two sub-categories if they are designed for commercial or archival purposes, while all the other scanners are considered just prototypes. As for many other acquisition systems, the main differences among scanners rely on the sensors and optics; meanwhile, cinematographic film scanners are characterized mainly by differences in the transportation system and the presence of an audio recording device. Motion picture film scanners can present different sensors (area array or linear; CCD or CMOS) and different optics systems, allowing overscan acquisitions with the frame edges. The pros and cons of sensors and optic systems strongly depend on their integration into the system, use, and overall maintenance. Furthermore, different archival materials present different features (e.g., a Super8 amateur film requires digitization parameters different from a negative feature film in 35mm), thus requiring a different level of sampling and quantization.

Cinematographic Film Softwares

Scanner transportation can present different features, like being spoketless and having a wet gate. Here, it is essential to notice that a possible difference between archival and commercial scanners relies mainly on transportation systems. Usually, spoketless scanners with wet gates are the best solution for archival material that is strongly damaged or degraded. Still, these systems require more digitization time and higher material handling (e.g., films might move slightly on spoketless reels). Also, in this case, the pros and cons of transportation features depend on the archive's materials and sources and the preservation aim.

Even if not specified in the FIAF scanner list, cinematographic film scanners strongly depend on proprietary software. In fact, even if some specific hardware features can be considered preferable when working with archival materials (e.g., transportation), digitization guidelines suggest acquiring images with particular quality standards. In the domain of motion picture film, the quality assessment, measurement, and evaluation of a scanner's final quality are totally left in the hands of the producers, who perform system calibrations, intervene in case of errors, and publish whitepapers with systems features and testings. Considering more standard documentation (FIAF Digital Statements [11], [12], [13]), some suggestions are provided for choosing scanner parameters (e.g., resolution, bit depth). However, standard quality assessments and regulations are still lacking. In this overview, it is fundamental to mention that some international standards, like FADGI [14], recommend scanning specifications for photographs, which can also be used for cinematographic film materials. Most standards and recommendations for digitizing motion picture film materials can be found in fragmentary and extremely specific ISO standards. Today, archives and film restoration laboratories rely on internal regulations without following commonly shared international guidelines.

ADX color film system

Modern commercial film scanners integrate the ADX system to digitize negative and inter-negative films. This model is used because (as Cineon previously) it allows us to correlate the exposure values registered by the sensor with film density values on specific constraints. In a few words, this system allows the generation of a positive digital copy of a negative film, corresponding to (i.e., simulating) the printed positive copy optically generated through the analog printing process. As the Introduction reports, obtaining a trustworthy digital intermediate allows significant data manipulation. Nevertheless, this analog-to-digital encoding can also be very useful in film digitization for restoration and preservation purposes (under specific conditions that will be analyzed in the following sections).

A digital positive ADX encoded image is obtained from a negative analog film through spectral responsivities based on modern film stocks, among other defined conditions (see further details in [15]). Thanks to this encoding, internal LUTs process the linear signal acquired by the scanner's sensor, which is transformed into logarithmic. At this point, some software also includes some color and tone enhancement or the application of specific gamma values in the signal transformation.

In the acquisition step, when obtaining a positive image from a negative or inter-negative film, the ADX system is quite always applied since it is a smart way to simulate the appearance of a positive film, considering film materials. The user can turn on or off the ADX encoding by deciding whether to obtain a positive image from a negative film.

In some system software, there is also the possibility to select the film stock from a database or to perform an automatic film stock identification, allowing the scanner to read and interpret the film's edge codes. In this case, the image processing is the same as ADX, but instead of using general spectral responsivities based on modern film stocks, the specific spectral responsivities furnished by the film producer are applied. In addition, in some cases, the image processing operated by the scanner can be controlled by the user setting specific parameters or applying user-defined LUTs.

Results

After the considerations presented in the previous section, it is clear that even if some automatic encodings and LUTs are integrated into scanners', the main decisions that will affect the digitization output are in the hands of the user.

This section reports an experiment to assess and better explain the motion picture film scanning process. Figure 1 shows the results of a test performed on grayscale densities of a KODAK Color Digital Intermediate film 2254 (negative). The negative film has been digitized using a Scanity HDR (dft) film scanner using different automatic and semi-automatic parameters in the scanner's software. This scanner has been selected since it is among the most widely used in film restoration laboratories and can represent the main features of the available commercial scanners.

The same 21 grays of the negative color film have also been analyzed through a pointwise spectrophotometer (CM-36dGV by Konica Minolta). The spectra of the frames have been acquired in transmittance in the range 360 - 740 nm, and applying the ADX encoding from [15], the ADX RGB values (16bit) have been computed for each spectrum of each one of the 21 frames. Thanks to this calculation, it has been possible to compare the RGB values obtained from transmittance spectra encoded into ADX with the actual RGB values obtained through film scanning.

The analog film has been scanned in POS (positive) and NEG (negative), thus obtaining a positive image from the negative film and a negative image from the negative film. Considering the POS images, thus the digital images obtained converting the negative film into positive, three different results have been obtained using the automatic setting (AUTO), adjusting the lights following the scanner operator guidelines (MAN), and performing a linear scanning (LIN).

The results show that the data linearity obtained in AUTO and MAN results from processing that can be reconducted to the Academy Density Exchange (ADX) system. In this case, the spectral responsivities based on modern color negative film stocks, have been used to encode the film frames from the scanner into the ADX system, trying to simulate the tones of the positive film stock corresponding to the negative scanned film [15].

Considering this image processing, it is fundamental to notice that when scanning a film using these parameters (which can often be related with the selection of a film stock from the scanner's software database), the output digital images (in DPX format) are not "raw", but present an in-processing enhancement. A similar result can be obtained in NEG, but in this case, the approximation error in encoding the film into ADX is related to an unusual situation where the user decides to obtain a negative image from a negative

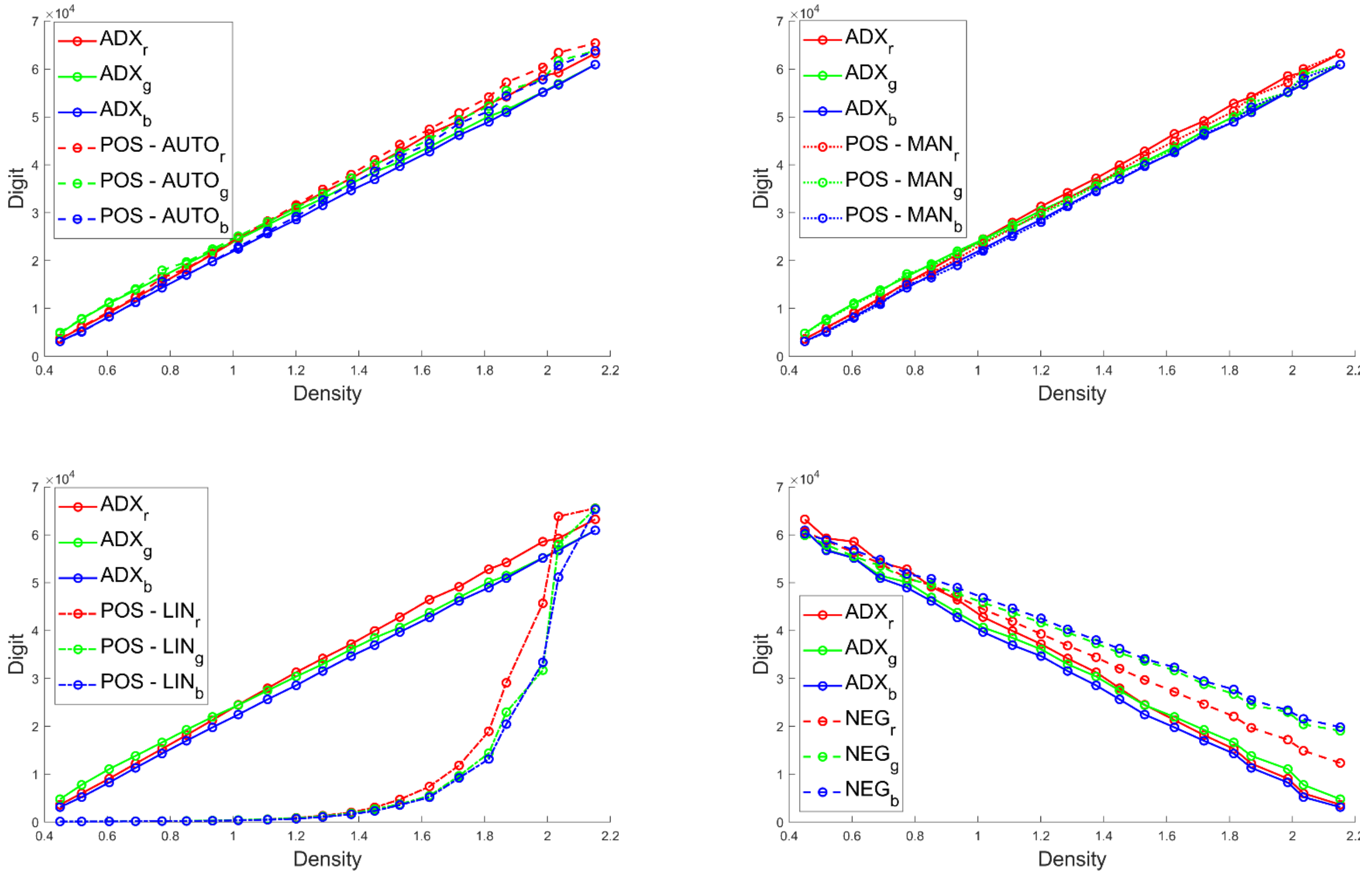

***Figure 1**. Example of film densities scanned using different parameters. On the top-left the RGB values of the acquisition made with automatic settings; on the top-right the RGB values manually setting the scanner's light; on the bottom-left the RGB values obtained using linear acquisition settings; and on the bottom-right the RGB values of the negative image. Both for positive and negative images, the values have been reported in relation with the optical density (-log(Transmittance)). In positive images, the highest density (black) correspond to the lightest positive values (white), the opposite for negative images.*

film. In this case, the NEG scanning should not have been performed using the ADX system or applying film spectral responsivities during digitization. The negative analog film contains all the information related to his materials, and linear scanning should have been preferable to preserve the analog film information without further processing the images.

Considering the LIN scanning, the obtained output images present a logarithmic distribution, faithful to the densities distribution of the analog film. In this case, the output frames can be considered "as much faithful to the original as possible" since the ADX encoding is not performed. In this case, some proprietary in-processing LUTs can still be applied, but the obtained images can be considered "raw" and proportional to the signal registered by the sensor.

Discussion

Considering the example reported in the previous section, it is important to notice that linear scanning can result in more consistent and replicable digitization results among different laboratories. The automatic and manual digitization strongly depend on the processing implemented and operated by the scanner software.

The ADX encoding can be very useful for modern film materials since we can reproduce and simulate the colors and tones of the corresponding positive film, reproducing its spectral characteristics. Understanding the image processing behind this operation is essential to make the digitization process straightforward and transparent. So, it must be clear that the image obtained is not a linear conversion of the negative film but a simulation of the positive, related to the use of a specific light source, specific negative materials, and a specific positive printing system (defined in [15]).

Linear scanning is preferable when the acquisition aims to obtain a digital image "as it is," thus, a negative image from a negative film or a non-processed positive image. But in this case, it must be mentioned that a further manual image processing step must be conducted. The obtained linear image represents raw data, which must be edited and adjusted depending on archival needs; thus, a post-processing step is necessary. In this case, the suggestion is to digitize the analog film linearly using the default light parameters (or any other parameters suggested by the scanner's production companies) and define a controlled and supervised post-processing step considering the restoration or preservation aim.

Performing linear scanning can also allow the user to assess the scanner's overall quality using high-density film materials or changing the acquisition parameters to define the scanner's sensor limit (e.g., many scanning systems can not correctly register density variations under 3.5 on color film materials). Understanding the scanner's limit is essential because different film materials can present different scanning requirements. For example, positive 35mm feature film copies can present high-density levels, while negative films can have a maximum density of around 2.0 or 2.2, like in the example reported in this work. Since scanners have been produced to digitize negative materials to be used in the ACES production workflow, the current sensors are sufficient to digitize and record modern films, as well as the ADX system allows correct positive reproductions to be obtained.

But what about historical films?

To digitize a nitrate film from the silent film era or a positive copy of a movie from the '60, the current scanner system and the ADX scanners may not be appropriate. Even if the scanner sensor is able to reach the density variations of the positive and negative film, the overall system can present several issues that could lead to acquisition errors. As explained in [16], scanner lights are usually RGB primary lights with wavelength peaks on the ADX's spectral responsivities highest absorbance levels; thus, scanner lights are not always suitable to digitize historical film colors and materials, which can present different physical characteristics than modern films.

In this case, it is still necessary to improve scientific research to create a digitization workflow that could be suitable for all kinds of cinematographic film materials, as it is done for other cultural heritages [17]. While developing new systems and scanner to improve film digitization, a solution can be to work with the instrument we have, being aware of the limits and performing more controlled digitizations.

More controlled digitization could be done by always acquiring the images in linear mode, using standard parameters to exploit the scanner sensor at its maximum, and performing image processing outside the scanner software environment. So, having "less" processing operated by scanner software, which often uses proprietary LUTs, could be useful for setting our processing methods, which take into account archival needs. In this case, for film digitization purposes, the acquisition of a positive film (from any historical period) can be made linearly, and the image processing could imply just some simple color balance or the application of a gamma, keeping all the operations of image edition for the restoration workflow. In the case of a negative film, a linear acquisition will lead to a negative image, which can be simply converted using linear curves. In this case, the result will always be a non-processed raw image. So, suppose the destination positive film material is known (e.g., for modern film). In that case, applying the ADX system is a useful solution, but if it is not known, each positive simulation will be an untrustworthy reproduction based on subjective evaluation or custom decisions.

Conclusion

This work briefly overviews and presents the cinematographic technologies and systems. Film scanners are derived from the digital industrial boost, and this forced many archives and laboratories to quickly convert their practices from analog to digital, totally implementing the technologies and systems used in motion picture film production. Considering colors and tone reproduction, the ADX system is among the most used to perform RGB encoding of negative film materials. This system allows the reproduction and simulation of the colors and tones of the positive film corresponding to the scanned negative using spectral responsibilities based on modern film stocks. Nevertheless, this system's great utility in creating digital intermediate copies of analog films and its extensive use in the archival domain, it could lead to several issues. The application of the ADX system on historical cinema could lead to incorrect simulation and color reproduction, which can be not only unsatisfying from an aesthetic point of view, but also untrustworthy.

For this reason, a more simple and linear scanning is suggested when working with historical film materials and positive films in general. For negative films, the ADX system is suggested just for modern films, and when digitization aims for a color reproduction of a positive film.

Applying a simplified film scanning workflow could also be coupled with a customized post-processing step aimed to provide an overall color correction to the digitized film in a more transparent way.

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References

[1] M. J. Bogdanowicz, C. Lurin and K. J. Alvut, "Full content film scanning on a film to data transfer device". US Patent US Patent 7,167,280, 2007.

[2] R. Patterson, "Understanding Cineon," *The Digital Intermediate Internet Guide. October,* 2001.

[3] G. Kennel, "Conversion of 10-bit Log Film Data To 8-bit Linear or Video Data," *The Cineon Digital Film System,* 1995.

[4] Academy of Motion Picture Arts and Sciences, "ACES," [Online]. Available: https://www.oscars.org/science-technology/sci-tech-projects/aces. [Accessed 2023].

[5] W. Arrighetti, "The academy color encoding system (ACES): A professional color-management framework for production, post-production and archival of still and motion pictures," *Journal of Imaging,* vol. 3, no. 4, 2017.

[6] A. Forsythe, "Considerations in the Design of a New Printing Density Metric and Encoding for Contemporary Motion Picture Applications," *Color and Imaging Conference,* vol. 17, pp. 296-300, 2009.

[7] N. Mazzanti, ""The Stuff That Dreams Are Made of"—Restoring Cinema Colors: A Roadmap for Real Research," *Heritage,* vol. 6, pp. 2520-2540, 2023.

[8] G. Fossati, From Grain to Pixel: The Archival Life of Film in Transition THIRD REVISED EDITION, Amsterdam University Press, 2018.

[9] A. Plutino, Tecniche di restauro cinematografico - Metodi e pratiche tra analogico e digitale, Dino Audino, 2020.

[10] FIAF, "Film Scanners," [Online]. Available: https://www.fiafnet.org/pages/E-Resources/Film-Scanners-Forum.html. [Accessed 2024].

[11] C. Ruivo, A. Gant, C. Blot-Wellens, T. Ganhão, D. Pozzi, U. Ruedel and K. Webb, "The Digital Statement - Recommendations for

digitization, restoration, digital preservation and access," FIAF Technical Commission, 2018.

[12] C. Blot-Wellens, C. Fournier, T. Ganhão, A. Gant, R. Mercês, D. Pozzi, C. Ruivo, U. Ruedel and K. Webb, "The Digital Statement Part II - Scanning for Preservation," FIAF Technical Commission, 2022.

[13] R. Byrne, C. Fournier, A. Gant and U. Ruedel, "The Digital Statement Part III - Image Restoration, Manipulation, Treatment, and Ethics," FIAF Technical Commission, 2022.

[14] FADGI - Federal Agencies Digital Guidelines Initiative, "Technical Guidelines for Digitizing Cultural Heritage Materials," 2016.

[15] SMPTE, "ST 2065-3:2020 - SMPTE Standard - Academy Density Exchange Encoding (ADX) — Encoding Academy Printing Density (APD) Values," *ST 2065-3:2020,* 2020.

[16] G. Trumpy and B. Flueckiger, "Light source criteria for digitizing color films," *Colour and Visual Computing Symposium (CVCS) IEEE,* 2015.

Author Biography

Alice Plutino (Phd, Università degli Studi di Milano, 2021) is MSCA Postdoctoral Fellow at the Faculty of Media Studies of the University of Amsterdam. Her research interests are Color Science, Colorimetry, Image Enhancement, Image Digitization, and Archiving, with a particular interest in Cultural Heritage applications. She is the author of the book "Tecniche di Restauro Cinematografico" and of several journal and conference papers of national and international relevance. She is an Adjunct Professor at Università degli Studi di Milano and Centro Sperimentale di Cinematografia, teaching digital film restoration and digital media conservation. She is a member of the Italian color group (Gruppo del Colore), deputy editor of the Color Culture and Science Journal (CCSJ), vice-coordinator of Division 1, and coordinator of Division 8 of NC CIE Italy. In 2023, Alice was awarded a Marie Skłodowska-Curie Postdoctoral Fellowship.