Early Cinema: spectral and colorimetric analysis of Tinting dyes for film restoration

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Abstract

Early cinema is often mistakenly imagined as completely silent and colorless. However, in reality, movies were not only accompanied by live music and live dialogue but also had the presence of color. One of the Early Cinema's main coloring techniques was tinting, which allowed the coloring of entire frame sequences with dyes. The colors used in tinting had nothing to do with the natural colors of reality, as producers focused solely on their visual effect and the meaning conveyed in the scene's narrative. Therefore, restoring films from this period is extremely difficult because, when the film fades or deteriorates over time, it is almost impossible to restore the exact colors without reliable information or references from the originals.

In this work, we perform a spectral and colorimetric study of the Tinting dyes used in Early Cinema, starting from the literature. The aim is to establish a scientific base that can aid and support the cinematographic restoration of these films during digital color reproduction. First, we conducted historical and bibliographical research on the early 1900s cinematographic dyes. We traced the dyes and their official production methods for tinting through the various editions of Eastman Kodak's Tinting and Toning of Eastman Positive Films book from 1918 to 1927. We then searched for the UV-Vis spectra of these compounds, from which we computed a colorimetric analysis. The RGB values of each dye allowed us to create a colormap to digitally recreate the effect of tinting on a black-and-white image.

This preliminary study shows that spectral and colorimetric data could be useful to digitally recreate the colors of the Early Cinema faithfully to the original colorants. Further investigations must increase the number of dyes and deepen the spectroscopic research, as the spectra of the chemical compounds used in this study do not necessarily correspond to the concentrations specified in the original coloring preparation recipes.

Keywords: Tinting, film restoration, dyes, early cinema

Introduction

Attempts to replicate colors in films in order to make the scenes shot appear more "natural" have been made since the early days of cinema. This impetus motivated the cinematographic industry to develop techniques for film coloring since the early 900s, first by hand coloring or with stencil physical films and afterward inventing new, faster processes such as the tinting coloring technique (Read, 2009).

This latter method was based on the use of organic and inorganic dyes, which colored the whole frame through chemical reactions, establishing a link between the hues employed and the narrative elements of the film. Visually, tinted films appeared completely colored, not just on the frame with the film images but also on the side perforations. This is because the coloring was done by specialized film laboratories where the pre-printed film was immersed in shallow vessels containing one of the solutions of the various colorants. This allowed the colorization of a whole sequence in a short amount of time without risking damage to the film through excessive handling. Due to its ease of usage, this coloring technique remained popular until the 1920s; with approximately 80-90% of films from that era featuring partially or entirely colored frames using this approach (Read and Meyer, 2000; Read, 2009).

Unfortunately, despite the faster rates of colorization, the colors used had nothing to do with the natural colors of reality: the authors used them solely for their visual impact and the significance they added to the scene's narration (Fossati *et al.*, 2018). And it is precisely because of these colors

that restoring films from that early period of cinema is so challenging. When a film fades or deteriorates over time, restoring the original hues is very hard due to a lack of preserved information from the original copy.
For this reason, in this study we aim to digitally replicate the color provided by the most commonly used dyes with a scientific base beginning with the spectral and colorimetric research of these substances, in order to help the restorers achieve a more accurate color reproduction during the restoration of these films.

Historical and bibliographic research

The first step of this study is historical-bibliographic research in the literature on the main colors used in the period and their chemical composition. In order to improve the accuracy of the colorant's tint in digital tinting, we specifically looked for the processes used to create the color baths in which the films were submerged. The numerous editions of Eastman Kodak's 1918, 1922, and 1927 books "Tinting and Toning of the Eastman Positive Films" (Eastman Kodak Company, 1918, 1924, 1927) provided a wealth of information that allowed us to identify specific dyes and their authorized production methods for the Tinting coloring. The main dyes described and used by Eastman Kodak Company are summarized in Table 1.

Table 1 - Dyes for tinting described in Eastman Kodak Company books, 1918, 1924, 1927.

Dye's name	Modern name	Color	Manufacturer
Amaranth 40F	Amaranth	Red	National Aniline Chem. Co., New York
Azo Rubine	Azo Rubine/ Carmoisine	Red	White Tar Aniline Corp.56 Vesey St., New York
Crocein Scarlet MOO	Acid Red 73	Red	National Aniline & Chem. Co., New York.
Lake Scarlet R.	Acid Red 26	Red	National Aniline &Chem. Co., New York.
Wool Orange GG	Orange G	Red/orange	National Aniline & Chem. Co., New York.
Wool Yellow Extra Conc.	Acid Yellow 23 / Tartrazine	Yellow	National Aniline & Chem. Co., New York
Naphthol Green B Conc.	Naphthol Green B	Light green	White Tar Aniline Corp., 56 Vesey St., New York.
Acid Green L	Guinea Green B	Green	National Aniline &Chem. Co., New York
Niagara Sky Blue	Direct blue 15	Blue	National Aniline &Chem. Co., New York

According to the original recipes described in the manuals, in order to create the color baths, the solid colorants had to be dissolved in a minimum volume of hot water and then filtered through a muslin to ensure that all of the solid residues were thoroughly removed. This process was crucial to achieving a smooth and even distribution of color throughout the bath. Once the solid residues were completely eliminated, the solution had to be diluted in the tank to the volume specified by the recipe while maintaining a constant temperature of 18°C. When the color bath was ready, parts of the film or the whole film were immersed for a determined amount of time. Every dye described in the books was used to create a specific tint. Each tint, along with the respective dye and amount of water used to obtain it, is reported in Table 2.

Only a few of the mentioned dyes (those that are still used as colorants today) could be tracked. For the found compounds, we gathered their spectroscopic and chemical data.

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Table 2 - Tints described in the Eastman Kodak Company books, 1918, 1924, 1927.

Tint	Components	Avoirdupois (g)/(L)	Immersion time (min)
Cine Red	Amaranth 40F Water	1000 200	3
Cine Red	Azo Rubine Water	400 200	3
Cine Scarlet	Crocein Scarlet MOO Water	400 200	3
Cine Orange Red	Lake Scarlet R. Glacial Acetic Acid Water	200 0,1 200	3
Cine Orange	Wool Orange GG Glacial Acetic Acid Water	200 0,1 200	1
Cine Yellow	Wool Yellow Extra Conc Glacial Acetic Acid Water	400 0,1 200	1
Cine Light Green	Naphthol Green B Conc Water	800 200	3
Cine Green	Acid Green L Water	800 200	3
Cine Blue	Niagara Sky Blue Water	400 200	1

Colorimetric characterization of the dyes

After the identification of the tinting dyes of the Early Cinema, we focus on their colometric study. Lacking access to a chemical laboratory for recreating the recommended concentration of colorant solutions as described in reference materials, we found all the absorption spectra of the colorants we could find on the online spectral database *SpectraBase* (Wiley & Sons, 2023) available at the website *https://spectrabase.com* and other scientific paper (Souto, 2010; Yang *et al.*, 2018; Leulescu *et al.*, 2021; Vannucci *et al.*, 2021).

We relied our colorimetric analysis upon these spectra, focusing on the wavelengths in the range of the visible spectrum (380–780 nm). First, we transformed the spectra from absorption SPD_A to transmittance SPD_T following the formula derived from the Lambert-Beer law:

$$\mathrm{SPD}_T = 10^{(-\mathrm{SPD}_A)} \quad (1)$$

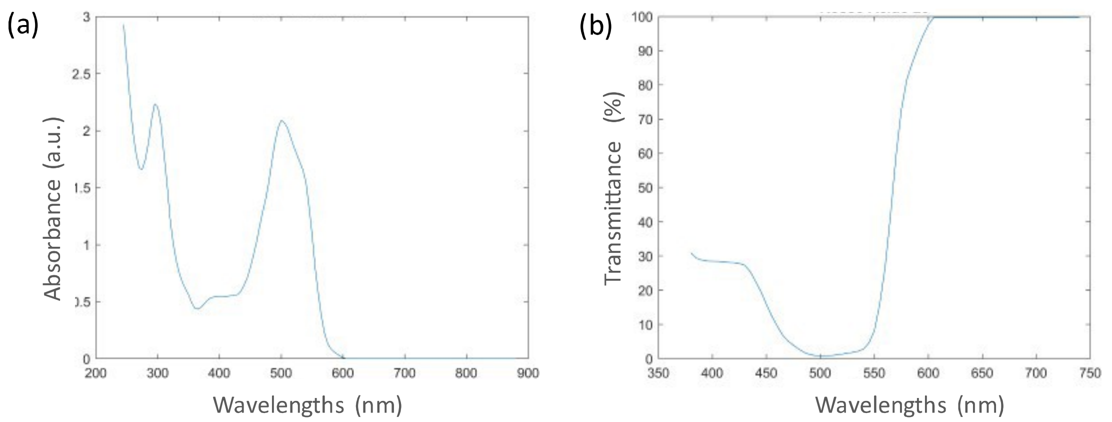

Figure 1. - Absorbance spectrum (a) and Transmittance spectrum (b) of *Acid Red 26* (Vannucci *et al.*, 2021).

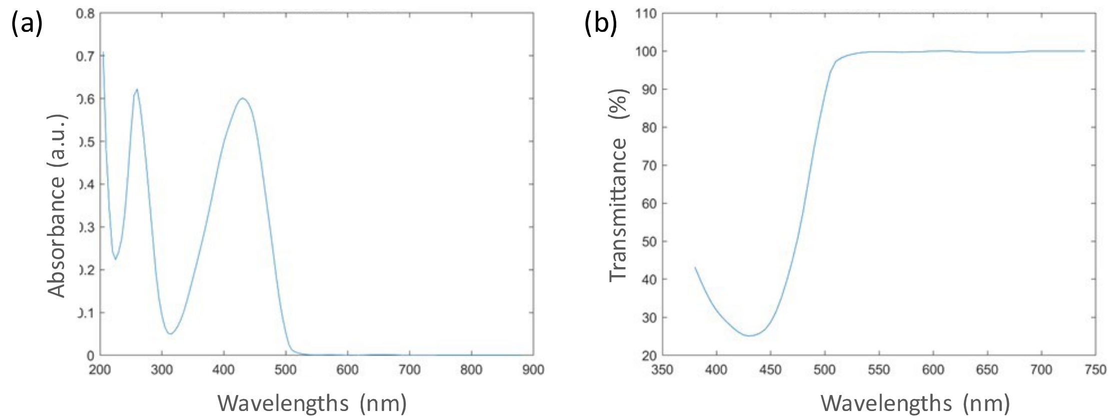

Figure 2. - Absorbance spectrum (a) and Transmittance spectrum (b) of *Acid Yellow 23* (SpectraBase, 2023).

Figure 1 and Figure 2 show two examples of spectra transformation for the colorants Acid Yellow 23 and Acid Red 26 respectively. In Figure 3, we have grouped all the transmittance spectra of each tint found in the Kodak books that are still used today as colorants.

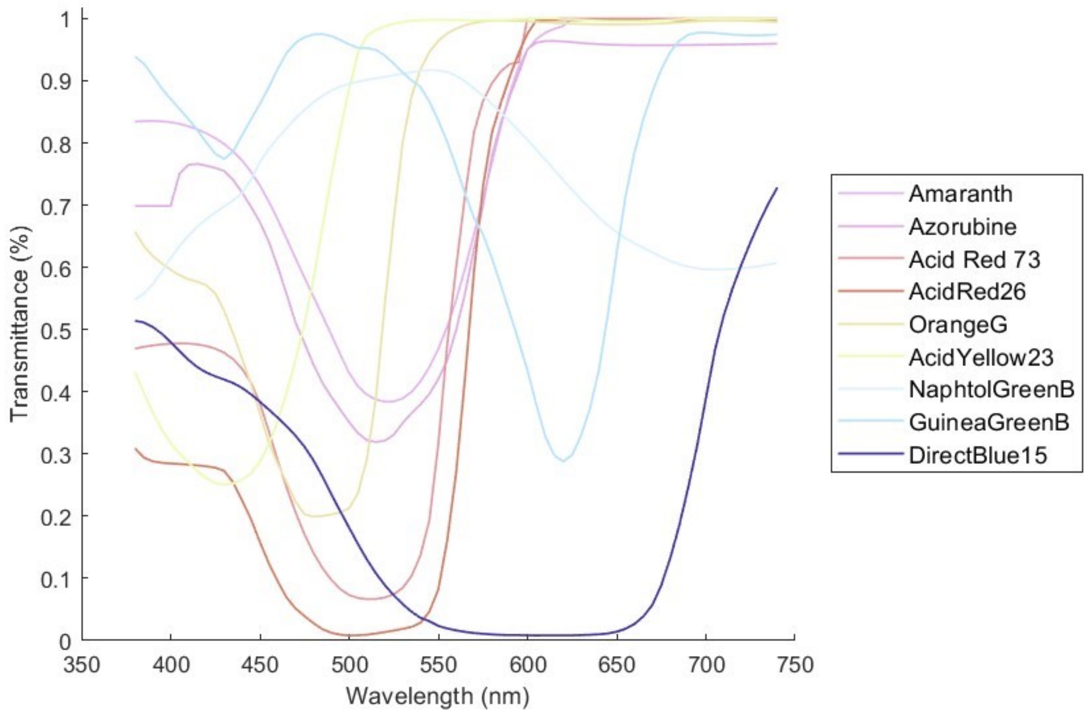

Figure 3. - Transmittance spectra of each tint found in (Eastman Kodak Company, 1918, 1924, 1927).

From the spectra, following the CIE guidelines (CIE TC 1-85, 2018) we then calculated the tristimulus values CIE XYZ, the chromaticity coordinates CIE xy and the RGB values of the colorimetric space sRGB, Adobe and Pro Photo, the most common RGB spaces. Table 3 reported coordinates XYZ and xy, while Table 4 summarizes the corresponding RGB values.
Several coordinates lie out of the gamut boundaries of all three color spaces (values reported in red in Table 3), especially for sRGB. As only a limited subset of ProPhoto RGB values falls beyond the gamut, we used the coordinates of this color space for the digital color reproduction. Out-of-gamut values were projected onto the surface of the color space constraining to 25 any values exceeding this threshold.

Table 3. - XYZ and xy coordinates of the dyes under analysis in the range [0,1].

Dyes	X	Y	Z	x	y
Amaranth	0.759	0.618	0.745	0.358	0.291
Azo Rubine/ Carmoisine	0.729	0.579	0.668	0.369	0.293
Acid Red 73	0.706	0.508	0.347	0.452	0.325
Acid Red 26	0.614	0.395	0.154	0.528	0.340
Orange G	0.823	0.825	0.391	0.404	0.405
Acid Yellow 23 / Tartrazine	0.829	0.965	0.424	0.374	0.435
Naphthol Green B	0.763	0.867	0.851	0.308	0.349
Guinea Green B	0.581	0.736	0.960	0.255	0.323
Direct blue 15	0.081	0.055	0.388	0.154	0.104

Table 4. – sRGB, Adobe RGB and ProPhoto RGB coordinates of the dyes under analysis. In red are the values out of the range (0,255)

Dyes	sRGB			Adobe RGB			ProPhoto RGB		
	R	G	B	R	G	B	R	G	B
Amaranth	270	180	218	248	178	216	229	180	241
Azo Rubine/ Carmoisine	270	171	208	247	169	205	225	172	227
Acid Red 73	289	145	149	259	144	148	226	151	158
Acid Red 26	286	109	96	252	109	96	212	122	100
Orange G	277	227	147	264	226	150	237	226	168
Acid Yellow 23 / Tartrazine	254	258	148	255	258	154	233	257	176
Naphthol Green B	220	246	227	227	246	227	219	242	259
Guinea Green B	143	238	243	176	238	243	182	227	277
Direct blue 15	-34	57	170	6	59	166	60	46	168

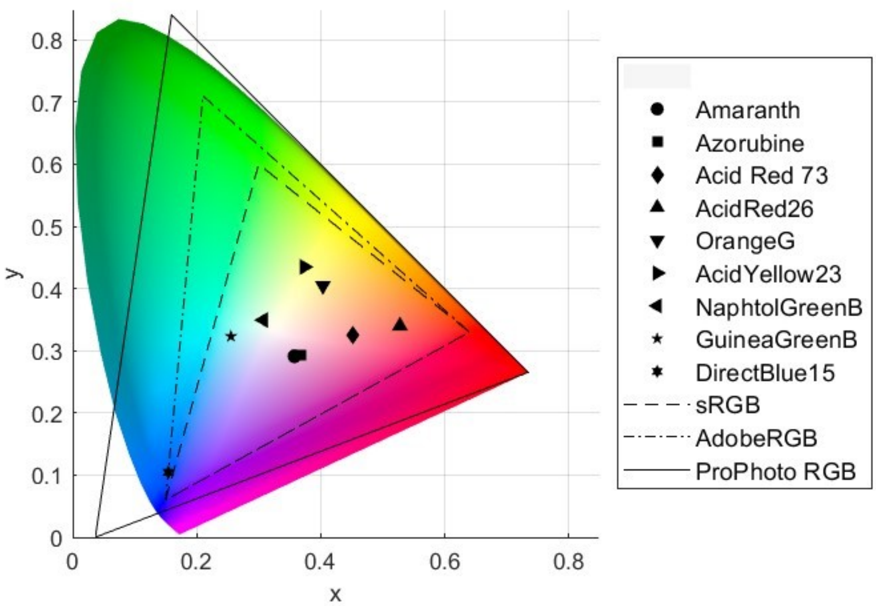

Figure 4. - Colorant's x, y values in Chromaticity Diagram with RGB spaces

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Digital tinting reproduction

To mimic early cinema tinting on a digital frame, we developed colormaps based on the RGB values of each dye as schematized in Figure 5. Since ProPhoto RGB has a wider gamut (see Figure 4), we worked in this color space. All the computations were done using Matlab. To include all the shades of a tint we selected all the colors lying on the line parallel to the Black-to-White major diagonal of the RGB color space (blue line) and passing through the coordinates of the chosen dye (black dot). All the colors out of the gamut were reported to the RGB cube surface (thus clipping to 0 the values below 0 and to 1 the values above 1) obtaining the orange line of Figure 6.

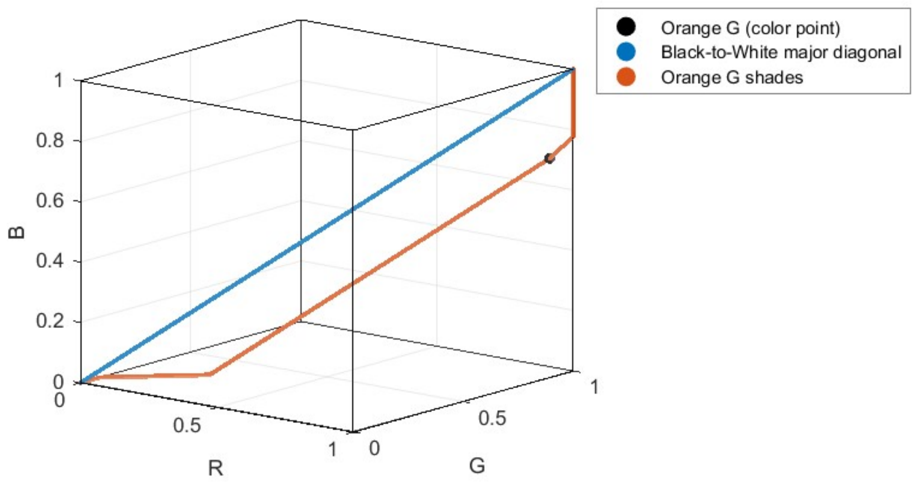

Figure 5. - Graphical representation of the method used.

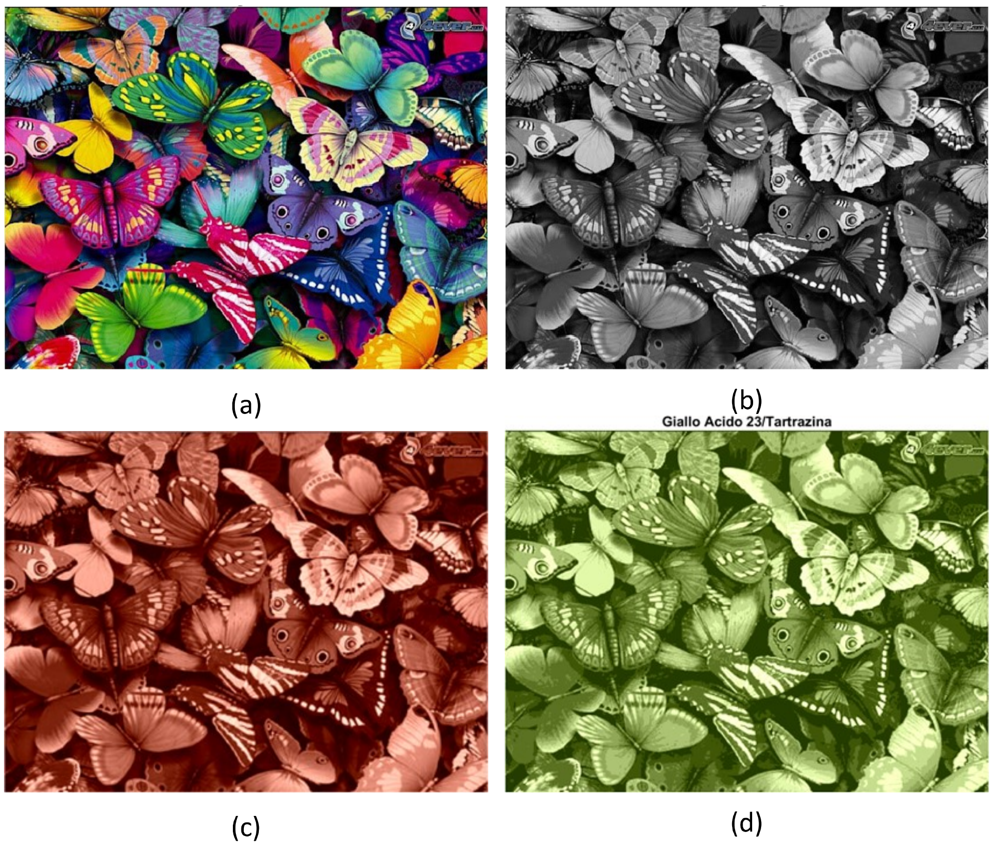

Figure 6. - (a) Original natural image; (b) image in grey scale; (c) image tinted with Acid red 26; (d) image tinted with Acid Yellow 23.

Better outcomes can be obtained by employing reflectance spectra that match the precise concentrations listed by Kodak. The spectra presented in this article did not exactly match the concentrations because our initial goal was to determine whether the method could be used. In reality, these spectra produced color simulations that were either more or less intense than they really had to be. A better and more realistic simulation of color tones can be achieved by measuring the reflectance spectra of several chemicals at various known concentrations.

Conclusion

In this paper, we have investigated a method to replicate the dyes used by Kodak in the tinting process of Early Cinema films. After bibliographical research and a colorimetric analysis of the dyes found in the literature, we digitally replicated the tints and then colored black-and-white images to simulate a frame restoration, proving that the method we used is valid. Whit these are preliminary results, we aim to establish a scientific foundation to assist restorers and experts in the field in achieving a more objective and faithful restoration, aligned with the historically employed materials and dyes. Further study would investigate a broader range of dyes, from other companies that Kodak and used outside the United States.

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