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A material investigation of color film technology through the Koshofer Collection

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Abstract

The Koshofer collection is an invaluable resource about the history of color film technology from the late nineteenth century until the 1980s, including film frames from early applied hand coloring, tinting and stencil coloring, to mimetic color processes such as Kinemacolor, Gasparcolor, and many other rare and popular color film stocks. Multispectral imaging in the visible range has been carried out to characterize the optical properties of the color processes, and an extensive microscopic examination allowed to reveal minute material features. These investigations highlight distinctive elements for the identification of some of the most significant historical color processes on film, and at the same time, offer crucial information for classical restoration techniques and for rigorous digitization strategies.

Keywords: *Optical microscopy, multispectral imaging, color film technology.*

INTRODUCTION

In analog film preservation and—more recently—in film digitization, producing copies of movies on modern color film stock or translating them into digital color spaces has proven challenging due to spectral mismatches between historical and current techniques. A deep understanding of the optical and material properties of film colors is necessary to establish effective methodologies for film preservation and restoration.

Although, in principle, any analytical chemistry technique (e.g., chromatography or XRF) can yield information on color chemistry (Ruedel 2017), two methods were chosen here for their ability to reveal in a non-destructive way the intimate link between color chemistry and visual appearance.

UV-Vis spectroscopy can chart the interaction of colorants with light, not only predicting the color appearance of a given film under particular illuminations, but also yielding an increased understanding of the aesthetics of historical color processes. Armed with this convictions, multispectral images were captured in the visible range with the methodology described in previous publications (Trumpy and Flueckiger 2018, Trumpy et al. 2021). The spectral resolution (~14 nm sampling interval) allowed to fairly trace the absorption curves of the samples, and the spatial resolution (up to 5X magnification on a 16-megapixel full-frame sensor) allowed to capture spectra down to a 2.2 μm^2 area. Microscopy enables researchers and restorers to 'zoom into' the photographic image even further to reveal its intimate structure and material properties tied to the spatial composition of the film stocks (Flueckiger 2012a, Flueckiger *et al.* 2020). The samples were observed and documented with transmission microscopy, using a Leica DM 2700 M microscope. Between the most plausible features of the analyzed historical color processes, the microscopic investigation also revealed curious oddities that stimulate further research.

The present contribution uses film frames from the Koshofer collection to look back at the evolution of film color technology. Gert Koshofer has been a prolific expert on film technology, who acquired a varied range of frames from rare and experimental historical color film stocks to more commercially viable and mass-produced ones. The collection consists of 161 samples categorized into 36 different color processes. The corresponding galleries have been included on the *Timeline of Historical Film Colors* (Flueckiger 2012b) containing the film frames, their micrographs and spectral measurements.

SELECTED SAMPLES FROM THE COLLECTION

Applied colors

Since its inception, the medium of moving images—and the cinema culture it grew into—was aiming at rendering images in color. Methods to selectively color silver-based monochrome images after development were implemented soon, based on staining the gelatin with suitable soluble dyes, either by hand or stencil, or literally 'bathing' the film. Redox chemistry allowed for replacing the silver grains with colored salts. These methods, alone or combined, established a wealth of early applied film colors (Read 2009).

Chromolithography

Chromolithography represents a very special case of applied colors on film, as the images are not created with a silver-halide photographic emulsion. This printing process was first adapted for the *laterna magica* and later used to produce early animation films. These films were usually very short and projected in loops (*litho-loops*). The Koshofer collection includes frames from three litho-loops that date back to around the first decade of the 20th century. Figure 1 reports the edge-to-edge color image of a sample with six primary colors: black, yellow, magenta, cyan, light cyan and beige. Other colors were obtained applying two primary colors, such as the green obtained adding yellow to light cyan. The plot in Figure 1 reports the spectral density values of the sample's yellow and light cyan and green (solid lines). By adopting a simple subtractive model, it is possible to confirm that the light cyan was applied to the whole table until the bottom black line, and the superimposition of a diluted yellow produced the green. In fact, the sum of the yellow spectral density with a dilution factor (0.65) and the light cyan spectral density gives a good match with the green spectrum (black dashed line).

A photomicrograph of another litho-loop sample is reported at the bottom of Figure 1. The film exhibits an extended landscape of craquelure that resembles the quintessential ageing of historical paintings. The typical 'spongy', irregular distribution of the color on the film emulsion is especially evident in the red section.

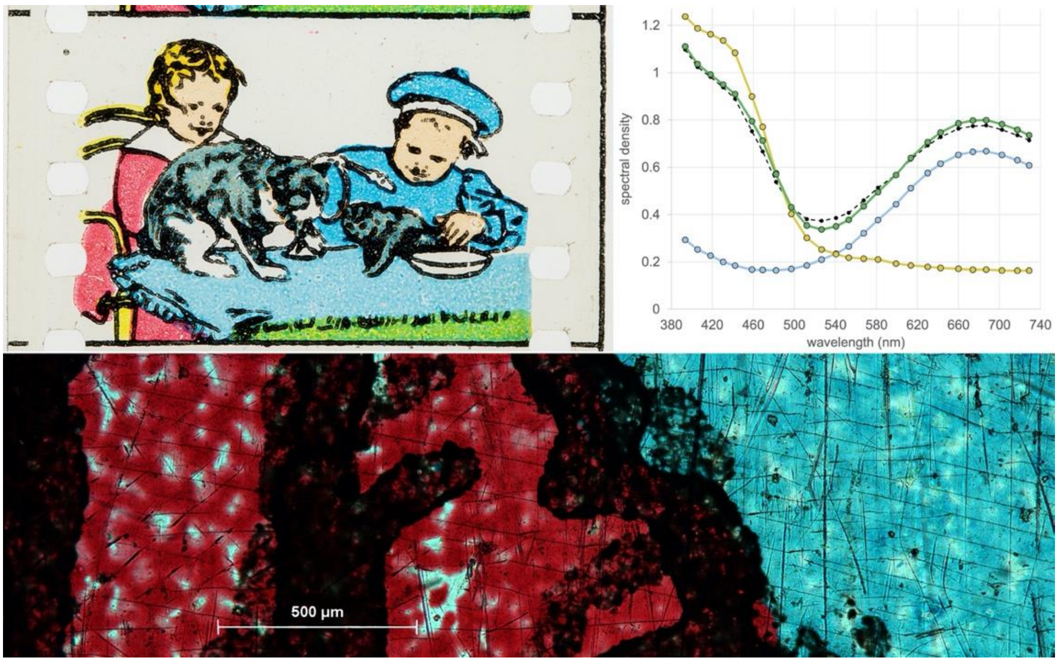

Figure 1: Chromolithographic samples - selected spectra and micrographs.

Mimetic colors

During the time in which applied colors were widely used, innovation continued and strove towards the so-called ‘natural’ or *mimetic* colors, by splitting spectral information into two to three - rarely four - components and recombining them into a colored rendition on the cinema screen with a large range of technical solutions. The combination was achieved either by admixtures of colored lights (additive color), or by filtering the illumination through layers of dye- or pigment-containing gelatin (subtractive color).

Additive processes

The principle behind additive processes that employ regular or irregular patterns of colored stripes or dots (*screen processes*) can only be understood via microscopic investigation.

Cinécolor film is the application of the 3-color mosaic screen process Autochrome to motion pictures. The Cinécolor frame reported in Figure 2 dates to around 1929. The color component that is meant to modulate the short visible wavelengths is actually a violet—instead of a blue. In fact, the transmittance values reported in Figure 2 indicate that the blue dye considerably transmits light around 650 nm. This distinctive feature limits the range of colors that the film can generate.

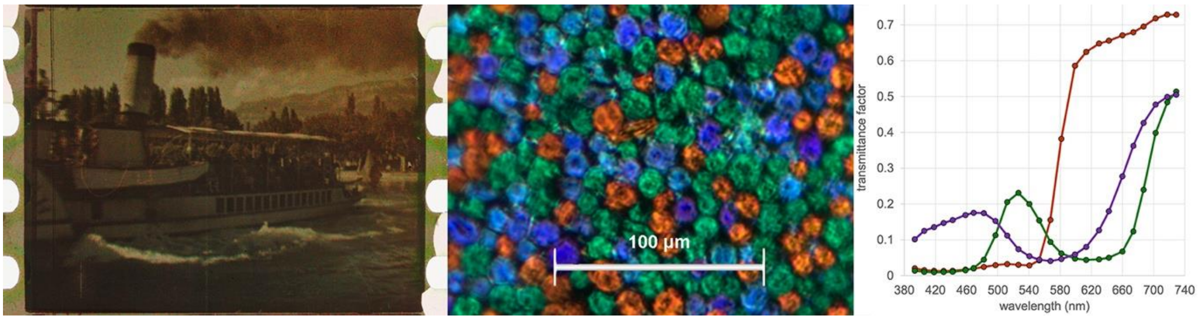

Figure 2: Cinécolor sample – Micrograph and dyes’ spectra.

The photomicrograph of the Cinécolor sample (Figure 2-center) depicts a constellation of multicolored particles appearing to be oscillating in a rhythmic choreography, despite being prosaically just transparent colored potato starch grains. The microscopic investigation highlights one of the problems that prevented the successful exploitation of this process. The starch grains tended to form clusters of the same color (Heymer 1933), leading to an uneven pattern that, when projected as motion picture, became significantly obtrusive to seamless perception.

In contrast, Dufaycolor is an additive three-color screen process with a regular pattern of thin colored lines arranged diagonally, which was in use between 1933 to 1958. Like Cinécolor, it was mostly used as a reversal process, but some years after its first introduction, a negative/positive Dufay process was also introduced (Dufay-Chromex 1938).

The micrographs and the chromaticity ranges of reversal and negative/positive Dufay are reported in Figure 3. The green component exhibits the most significative difference. The chromaticity of the aqua-green primary of Dufay reversal is close to the chromaticity of its blue primary, resulting in a strong compression of the color range in comparison to its negative/positive version.

Dufaycolor’s regular structure is visible in the micrographs. The diagonal lines are positioned at an angle of 23°, with one line—depending on the year and location of production—overlapping the other two. The areas of the patches are balanced for neutral color rendition.

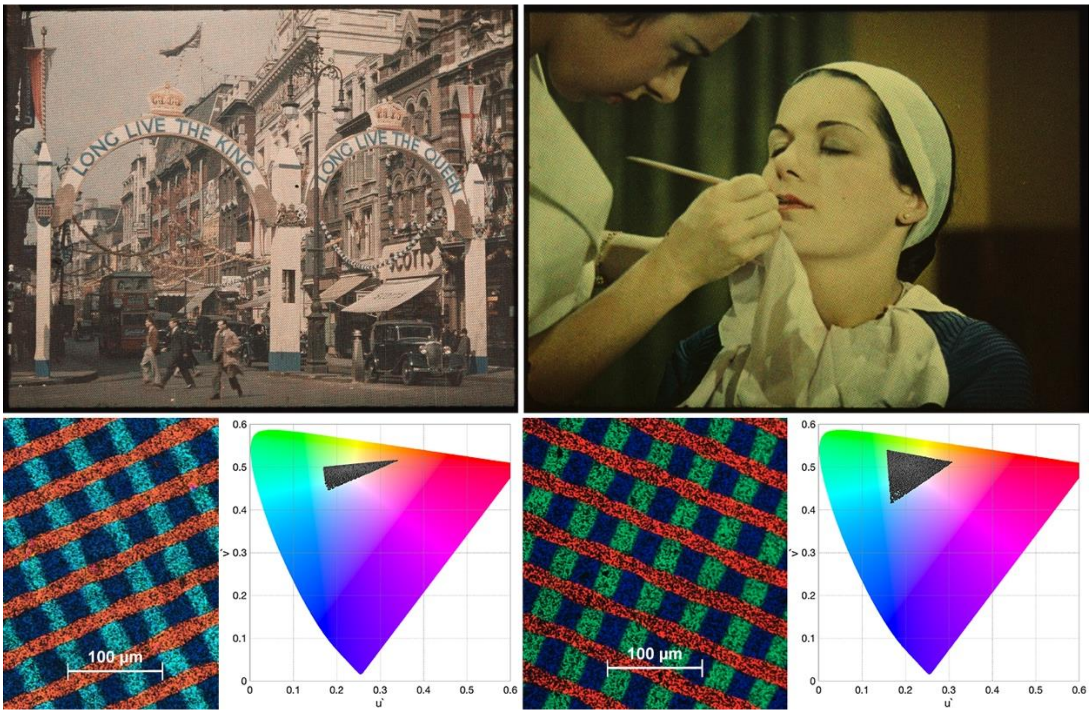

Figure 3: Dufaycolor reversal (left) and negative/positive (right) – Corresponding micrographs and chromaticity ranges (bottom).

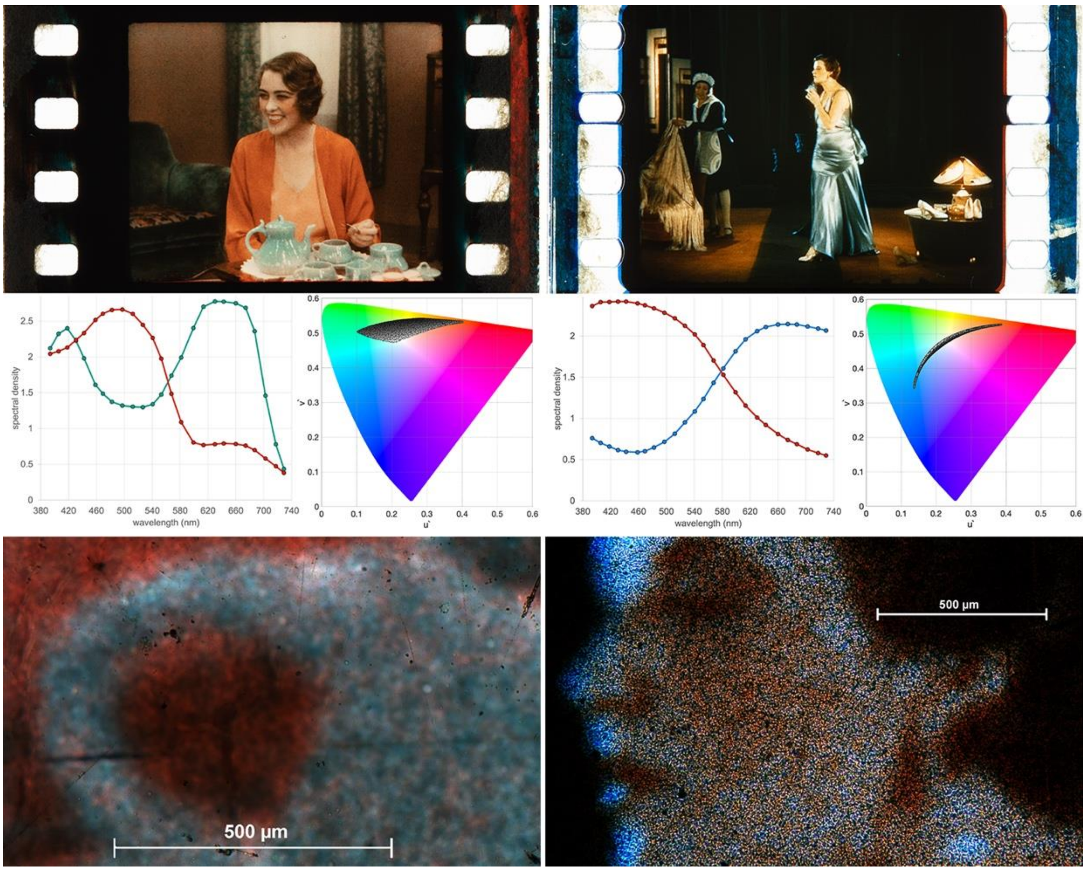

Figure 4: Two-color Kodachrome (left) and Multicolor (right) – Pure dyes' spectra, chromaticity ranges and micrographs.

2-color subtractive processes

Two-color processes only reproduce a limited color range, leading to very characteristic aesthetics. The visible spectral range is split in two sub-ranges, and in each sub-range the transmitted light is modulated by one of the two colorants. The Kodachrome Two-color, invented in 1915 (Ryan 1977), employs a red-orange colorant that mostly absorbs below 560 nm and a green colorant that mostly absorbs above 560 nm (see Figure 4-left). The sub-range modulated by the green colorant also includes a small additional region below 440 nm. The image of this two-color film frame renders a formidable sense of color tridimensionality, which is corroborated by the quite extended chromaticity range reported in the left side of Figure 4. The photomicrograph of the Kodachrome sample illustrates a fleeting/elusive textural quality. The large size of the image particles is indicative of the low emulsion speed of the process, and the patchy structure appears quite blurred in magnification.

Multicolor is a double-coated subtractive two-color process that was in use between 1928 and 1934 (Otis 1931). The cyan and red dyes create well separated sub-regions of the visible spectrum. The absorbance curves cross each other smoothly around 580 nm (see Figure 4-right). The micrograph of Multicolor (Figure 4-bottom/right) resembles a piece of textile embroidered with golden thread work, containing strong highlights and extremely deep darks. The toned image particles confer a characteristic granular texture that reminds colored frosted glass, with the two color records often slightly displaced thereby creating color fringes.

3-color subtractive processes

Subtractive three-color processes became the dominant standard in photography and film throughout the second half of the 20th century, with Technicolor being the market leader for two decades until the mid-1950s. In Technicolor prints, yellow, magenta and cyan dyes were printed in succession through a dye-transfer process onto a blank film. The dyes modulate the short, medium and long wavelengths respectively (see Figure 5). The micrograph of the Technicolor No. V color chart from 1956 (Figure 5-bottom/right) has a characteristic patchy, halftone-like pattern resulting from the printing process. The photomicrograph resembles a crystallized material, like a layer of a suddenly frozen liquid. These frames depict a test print composed of the three images from the individual printing matrices. The misalignment is responsible for the color fringes visible in the micrograph of the combined image.

CONCLUSION

Investigating the material properties of color film yields highly significant results, enabling archivists and restorers to identify historical film stocks by comparing unidentified film prints in their holdings with the documentation discussed here and published online. Furthermore, such investigations need to be integrated into film digitization/restoration practices more rigorously. Image texture and characteristics are important factors of a film material's specific aesthetics and color appearance, necessitating minute attention to each element's genealogy and materiality.

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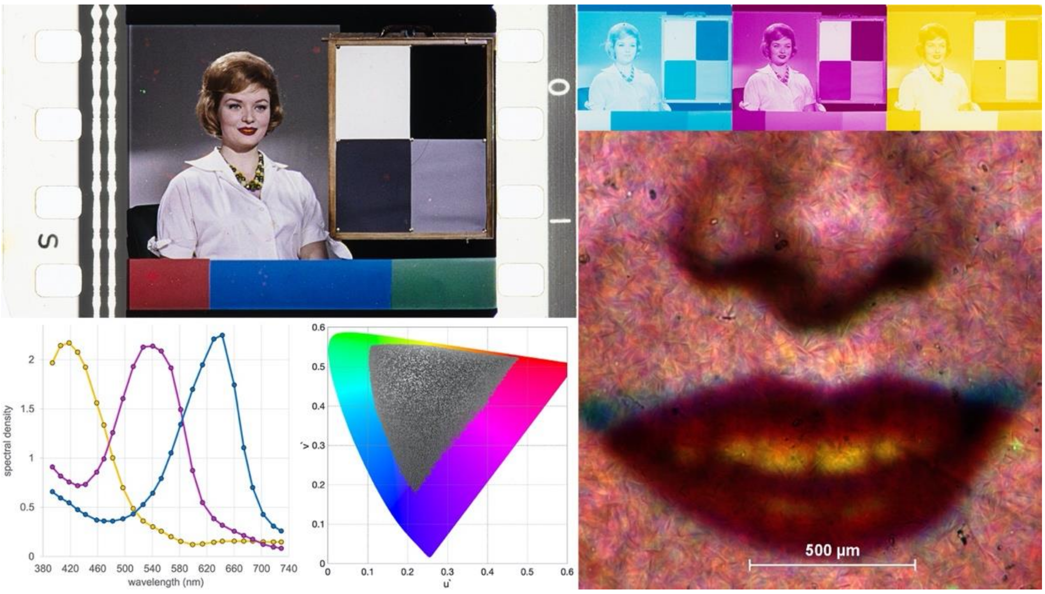

Figure 5: Technicolor print – Pure dyes' spectra, chromaticity range, individual matrices and micrograph of the composite print.

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