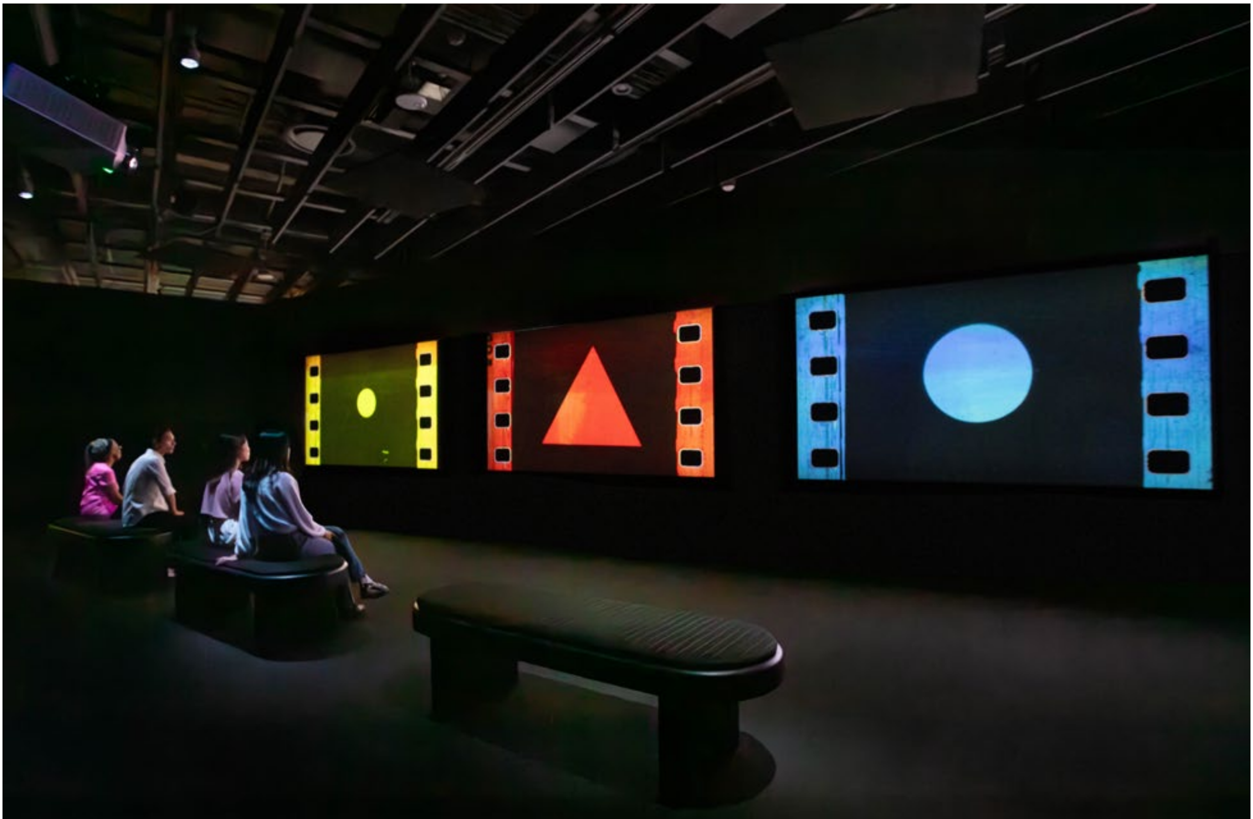
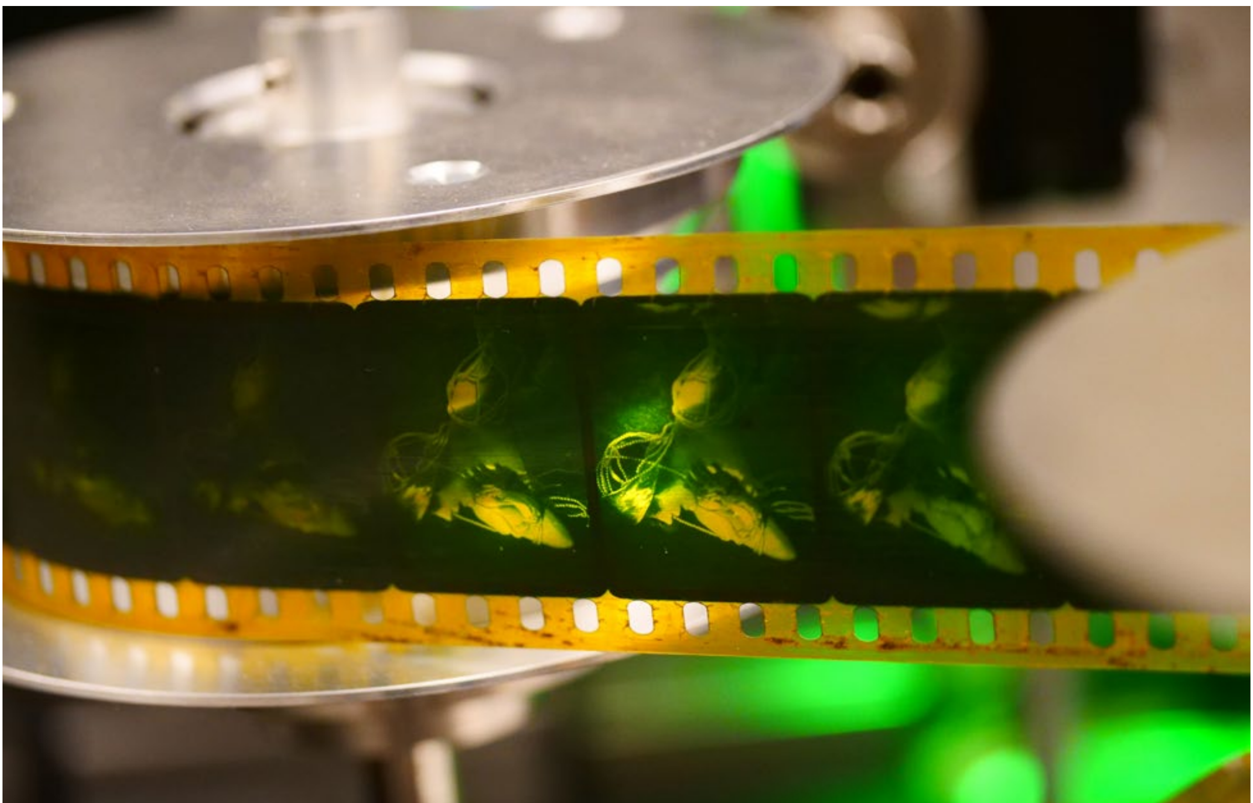


Multi-spectral scans at the Color in Motion exhibition, Academy Museum of Motion Pictures, Los Angeles.



Multi-spectral scanning respects the material foundation of the film elements to be scanned.
Film: Tinted and toned nitrate print of *Venus of the South Seas* (James R. Sullivan, 1924).

The Case for Multi-spectral Scanning of Historical Colour Films

Barbara Flueckiger, Giorgio Trumpy, Lutz Garmsen, David Pfluger, Martin Weiss, Julius Muschaweck

Barbara Flueckiger, **Giorgio Trumpy**, **Lutz Garmsen**, **David Pfluger**, **Martin Weiss**, and **Julius Muschaweck** have been collaborating for several years on a number of research projects dedicated to film colours and their digitization: DIASTOR (2013–2015), ERC Advanced Grant *FilmColors* (2015–2021), ERC Proof-of-Concept VeCoScan (2018–2020), and Bridge Discovery *Scan2Screen* (2021–2023). In 2023, they founded two start-ups in Switzerland and the U.S.

In workflows for digitizing historical colour films, the optical principles of scanners remain underexplored and poorly documented, despite extensive research on the digitization of analogue films by scholars, restorers, and archivists over the last 25 years.

The FIAF Technical Commission's *Digital Statements*,[1] especially *Part II. Scanning for Preservation*,[2] rightly highlight this gap, noting the opacity of scanners' operating principles and some of their implications for colour accuracy. While the *Digital Statements* address the digitization of chromogenic negatives using Bayer sensors or monochrome sensors with RGB flashes for the separate red, green, and blue channels, they overlook critical considerations for historical film stocks and colour processes. A scanner study carried out by the authors within the framework of a research project retrieved as much information as possible about the spectral characteristics of eight widely used commercial film scanners, relying on documentation provided by the manufacturers.[3] These systems predominantly rely on narrow-band Light Emitting Diodes (LEDs), with exceptions like the Scanity, which offers two different LEDs in the long wavelength spectrum at 690 nm and 660 nm for chromogenic positives and negatives, respectively. The Kinetta combines three narrow-band LEDs with a "white" LED but operates with a Bayer sensor. The D-Archiver applies a "white" 4,300 Kelvin LED array. Meanwhile, the specifications of the DFT Polar HQ included in the manufacturer's brochure only mention an "RGB-IR LED (Cold) diffuse light source" without detailing the spectral properties.

However, the *Digital Statement Part II* rightly notes that even advanced workflows fail to fully capture the properties of hand-painted and tinted prints, and some colour

1. <https://www.fiafnet.org/pages/e-resources/digital-statement.html>.
2. Camille Blot-Wellens, Caroline Fournier, Tiago Ganhão, Anne Gant, Rodrigo Merces, Davide Pozzi, Céline Ruivo, Ulrich Ruedel, Kieron Webb, "The Digital Statement Part II. Scanning for Preservation", *Journal of Film Preservation*, No. 108, April 2023, pp. 19-31.
3. Barbara Flueckiger, David Pfluger, Giorgio Trumpy, Simone Croci, Tunç Aydın, Aljoscha Smolic, *Investigation of Film Material–Scanner Interaction*. Zurich (CH): University of Zurich/University of Basel/Swiss Federal Institute of Technology/Disney Research Zurich, 2018, <https://doi.org/10.5167/uzh-151114>.

negatives, as they "fall outside its [i.e. the workflow's] range",[4] but this is also true for many other film stocks, as we elaborate below.

In this paper, we advocate a multi-spectral scanning approach that combines precise optical setups and workflows to address these limitations, ensuring scientifically rigorous digitization for historical colour films.

The FIAF *Code of Ethics* states: "When copying materials for preservation purposes, archives will not edit or distort the nature of the work being copied. Within the technical possibilities available, new preservation copies shall become accurate replicas of the source materials. The processes involved in generating the copies, and the technical and aesthetic choices which have been taken, will be faithfully and fully documented."[5]

The process of translating analogue film materials into the digital domain comes with inherent epistemological limitations. Critical details, such as the material composition of film stocks, the chemical compounds – dyes and pigments – embedded in the emulsion(s), and the layering of elements within an analogue film element, are not captured by the digitization process. These aspects, however, should be meticulously documented as an integral part of the restoration workflow.

Given the intrinsic limitations of digitization, the most effective approach is to recreate the (colour) rendition of the historical exhibition element (more often than not a vintage release print) as it would have appeared projected on the cinema screen. To align with the core principles of restoration ethics – transparency, reversibility, and documentation – it is essential to establish a workflow where every step of the scanning and postprocessing stages is systematically recorded. This includes technical configurations and decisions, allowing for minimal subjective intervention and maintaining a clear, reproducible process.

At the same time, it is crucial to develop sustainable approaches that will comply with future standards and workflows, ensuring adaptability in the ever-evolving, dynamic field of digital technologies and formats.

SPECTRAL CHARACTERISTICS OF HISTORICAL FILM COLOURS

A thorough understanding of the broad variety of historical film colour processes is vital for informing the theoretical framework behind digitization technologies. It requires combining expertise about the history of film colours with colour science, optics, and technical innovation. An interdisciplinary mindset is mandatory to make significant progress to improve digitization technologies as regards both hardware and software.

Spectral measurements are one of the first and most important steps towards understanding the physical nature of historical film colours. Only by documenting the various spectral properties embedded in film stocks can one implement a digitization chain sufficiently adapted to their unique characteristics.

Following the Second World War, chromogenic film colours became dominant as the Allies and other countries exploited the German patents for Agfacolor.[6] This shift narrowed the vast range of earlier spectral characteristics to a more standardized set.

4. Blot-Wellens et al., op. cit., p. 23.
5. *FIAF Code of Ethics*, Third Edition. Brussels: Fédération Internationale des Archives du Film, 2008, pp. 5-6.
6. See, for instance: Anna Batistová, "Glorious Agfacolor, Breathtaking Totalvision and Monophonic Sound. Colour and "Scope" in Czechoslovakia", in: Simon Brown, Sarah Street, Liz Watkins, eds., *Color and the Moving Image. History, Theory, Aesthetics, Archive*. New York/London: Routledge, 2013, pp. 47–55; Heather Heckman, *Undervalued Stock. Eastman Color's Innovation and Diffusion. 1900-1957,* PhD thesis, University of Wisconsin-Madison, 2014; Josephine Diecke, *Qualitätsfilm aus Wolfen. Die diskursive Konstruktion von Agfacolor und Orwocolor im globalen Spannungsfeld, 1936-1990*, PhD thesis, University of Zurich, 2022.

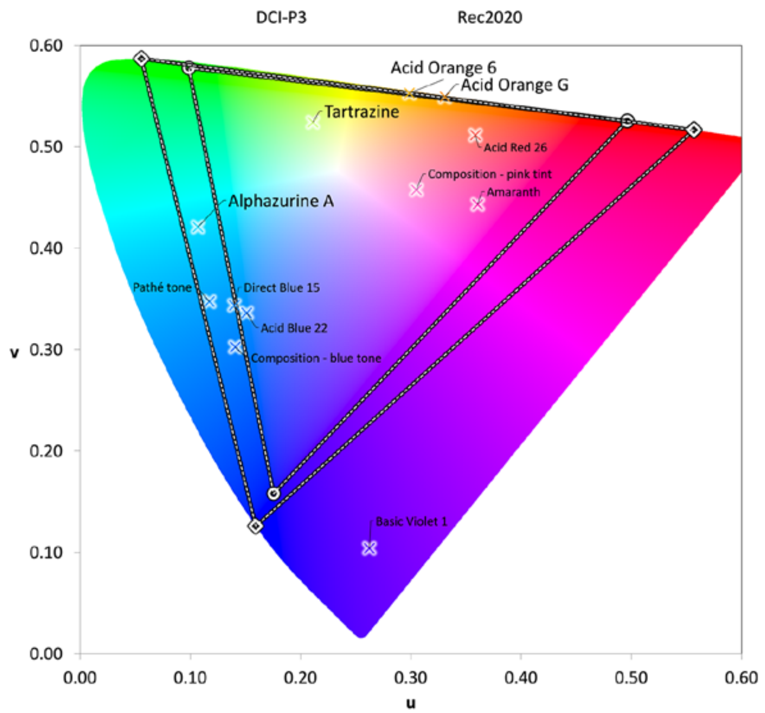


Fig. 1. Various chromaticity values of applied colours plotted in the CIELUV space together with PCI-D3 (inner triangle) and Rec. 2020 (outer triangle).

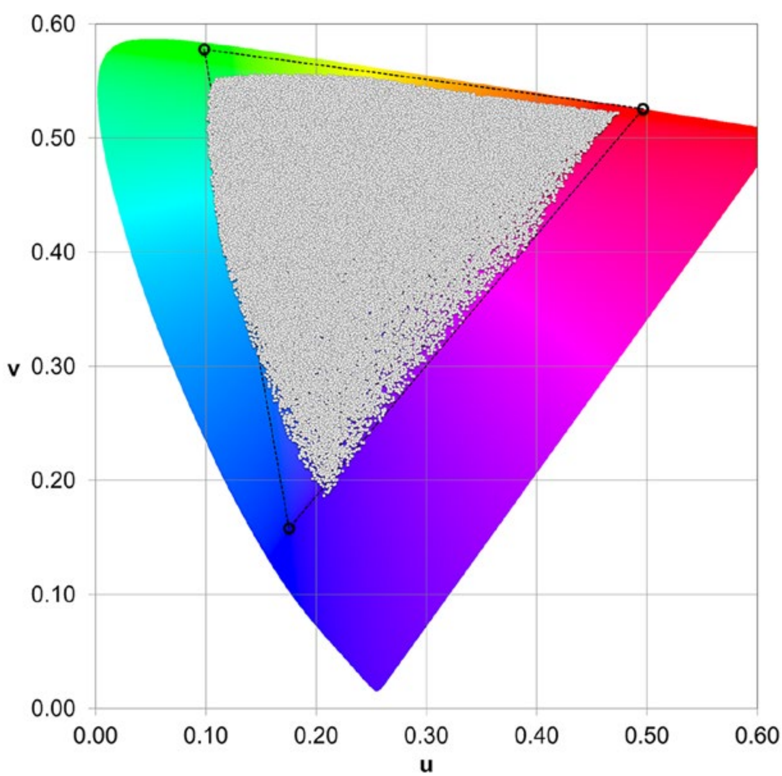


Fig. 2. Chromaticity values of Technicolor No. IV plotted in the CIELUV space with PCI-D3.

All previous film stocks employed a wide range of dyes and pigments, encompassing applied colours such as tinting, toning, and hand- or stencil-colouring. Additionally, mimetic processes that aim at recreating the visual impression of the scene in front of the camera by a chain of physical and/or chemical steps, from the camera set-up to the composition of negative and positive film stocks and their development in post-production, featured distinct spectral properties that shaped their unique visual characteristics (such processes, also known as "natural colour", include two- and three-colour systems like Technicolor No. II through No. V and Gasparcolor). It is crucial to note that variations in spectral properties extend across all historical film stocks, not just the earliest examples, countering the widespread assumption that such issues are limited to applied colours. These idiosyncratic properties set them apart fundamentally from modern chromogenic stocks.

Measurements reveal the differing spectral distributions and confirm that historical film colours frequently extend beyond the boundaries of contemporary digital colour spaces (DCI-P3, Rec. 709, and Rec. 2020) as well as the gamut of display technologies, including digital cinema projection. While Rec. 2020 accommodates certain dyes and pigments, particularly in the blue-green spectrum, other historical colours remain unrepresented. (Figs. 1 and 2)

MULTI-SPECTRAL SCANNING

As Nelson Goodman argued, digitization is inherently a selection process.[7] Certain values of an object or document are considered, while others are omitted. This epistemological mechanism is not unique to digitization; it underpins all measurement systems and even human cognitive processing, which focuses on specific information and disregards the rest. Goodman's metaphor of a fever thermometer – which targets a certain range of temperatures and translates them into actionable steps – illustrates this concept. While analogue systems allow continuous refinement within their limitations, digital systems "hardwire" these steps into a binary code, losing any information that falls outside their range.

This metaphor helps contextualize the benefits (and limitations) of multi-spectral scanning. It is useful to think of a scanner as a measurement system that extracts data points from an object based on its physical properties, and a protocol that assigns binary values to these data points, interpreting them to produce meaningful results. More simply, a scanner measures the physical data of the film and, through signal processing, calculates a visual rendering of the film by mapping that data into a colour reference space. Thus, several interdependent steps must be calibrated for accurate results.

A multi-spectral system's spectral bands represent the system's sensitivity to specific radiation wavelengths. Various components, such as the illumination's spectral power distribution, sensor quantum efficiency, filters, and any other component that selectively transports radiation wavelengths, define these bands and directly affect the colour rendition. This rendition must align with the human visual system.

In principle, three spectral bands can suffice for accurate colour description. This is true if colour targets are used to adopt colour management workflows.[8]

The three spectral bands in most scanners, however, miss crucial spectral information present in historical colour film stocks. These scanners, optimized in the early 2000s for the digital intermediate (DI) workflows in the transition from analogue to digital filmmaking, often fail to capture or distort spectral information outside their narrow-band illumination. (Fig. 3)

7. Nelson Goodman, *Ways of Worldmaking*. Indianapolis: Hackett Publishing Co., 1978.

8. Abhay Sharma, *Understanding Color Management*. Hoboken (New Jersey): Wiley-IS&T, 2017.

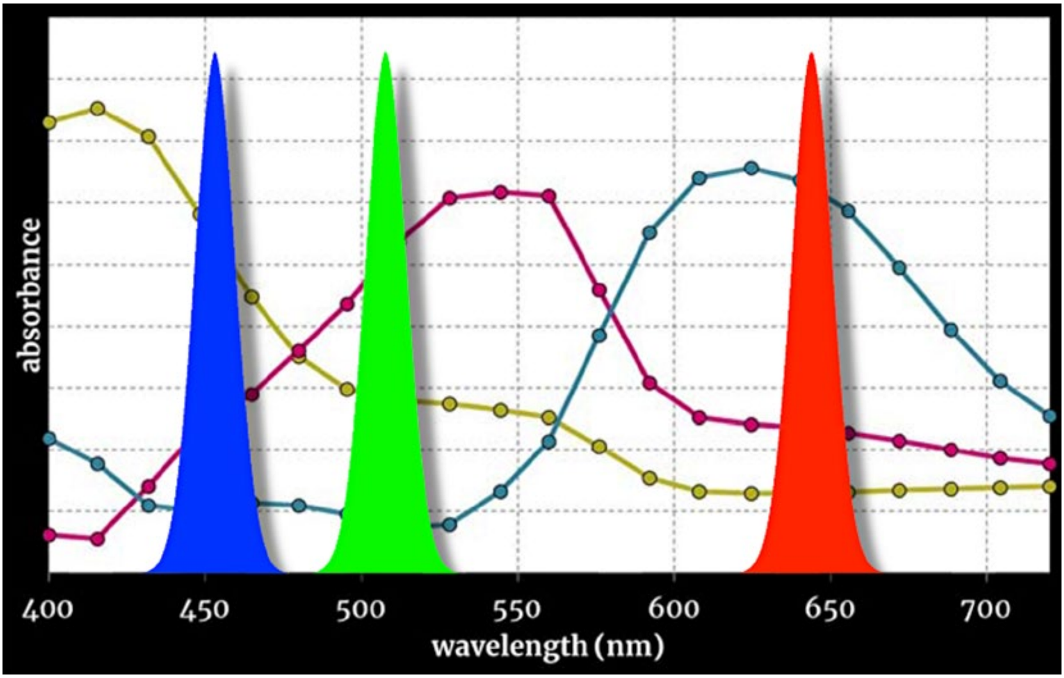


Fig. 3. Measurement of spectral absorbance of Gasparcolor with typical spectral bands of RGB illumination shows that crucial information can be lost with only three bands.

Consequently, colour rendition is typically reconstructed in colour correction after scanning. Reference prints are often visually assessed on the inspection bench backlit by an LED light panel, such as a small ARRI SkyPanel which combines three LEDs with a broadband "white" LED. For tinting and toning, standard collections of filter gels – for instance the *GamColor Standard Swatchbook of Lighting Gel Filters and Diffusion* – are used as intersubjective references for visual colour impressions. Each of these practices lacks standardization and relies heavily on human judgment. This introduces variability and subjectivity into the process, deviating from a clear-cut scientific protocol. From the outset these practices aim to adjust compromised data resulting from the lack of a comprehensive and standardized optical configuration of the scanner. Even a well-trained eye cannot deliver absolute colour accuracy because colour perception relies on the principal properties of the human visual system, which are inherently relational and context-dependent. These properties make absolute colour judgments impossible. A scientifically rigorous workflow eliminates human judgment, enhancing efficiency through an automated rendering pipeline.

To ensure authenticity and long-term adaptability, capturing more evenly-spaced bands across the entire visible spectrum is essential. Sufficiently documenting the spectral characteristics of the dyes and pigments in colour film stocks is the foundation not only for a successful rendering pipeline that provides authentic results, but for the long-term perspective to safeguard and adapt the digital data to future standards and workflows.

But how many bands do we need in theory and in practice?

Standardized digital imaging procedures suggest around 30 spectral bands for colour accuracy without colour targets.[9] The Commission Internationale de l'Éclairage (International Commission on Illumination,

9. CIE Technical Committee TC 1-38, *Recommended Practice for Tabulating Spectral Data for Use in Colour Computations.* Vienna: Commission Internationale de l'Éclairage, 2005.

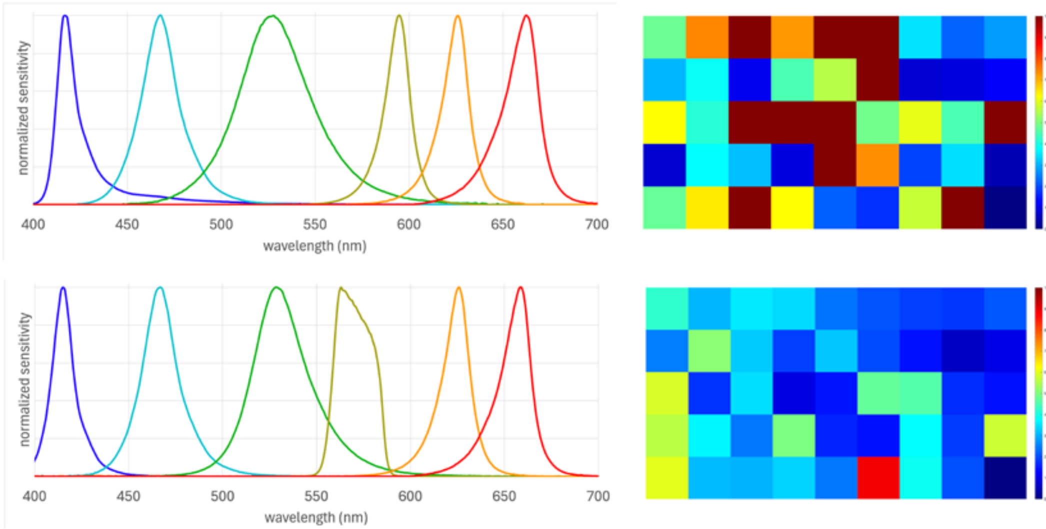


Fig. 4. Two sets of six spectral bands (left) and their corresponding color accuracy, represented as CIEDE2000 heatmaps (right) show that even slight mismatches of the LEDs can have severe consequences (above).

abbreviated to CIE) suggests measuring transmittance at a minimum spectral step of 10 nm in the visible range.

In a previous experimental scanner design by the authors,[10] 25 spectral bands were captured through a linear variable filter (Schott Filter Veril S200) illuminated by a plasma illumination (HPLS345 High-Power Plasma Light Source and 5 mm Liquid Light Guide). To evaluate the results of this spectral configuration, we conducted focus groups to assess test screenings of different film stocks and colour processes – tinting, toning, Technicolor No. IV, chromogenic films – in butterfly projection, the digital renditions and the analogue originals projected side-by-side (on a DCI-compliant Christie 2K cinema projector and Kinoton FP30 respectively). Three focus groups were gathered based on area of expertise: film historians, restorers, and archivists; colour scientists and colourists; and technicians and scanner manufacturers. They were then presented the full spectral range based on the 25 bands, plus incremental reductions down to six bands, and filled out a questionnaire to determine the smallest sufficient number of bands necessary for a convincing result.

Exploiting advancements in LED technology, the authors propose using 7 or 8 bands to achieve sufficiently accurate colours without colour targets.[11] While theoretical requirements might encounter practical limitations imposed by available LEDs, careful selection of LEDs can significantly mitigate these constraints. One of the advantages of a comprehensive spectral set-up in film scanning is the possibility to select a subset to put in practice the necessary alternative of colour separation. By selecting three narrow bands (red, green, and blue), it is possible to properly extract the colour information from negatives as in DI workflows.

Selecting the correct type of LEDs is crucial for the subsequent rendering. (Fig. 4) The required bands stretch from deep blue into deep red. However, no single LED chip technology covers this wide spectral band. InGaN LEDs cover blue to green, and InGaAlP LEDs cover orange to red, but a "yellow-green gap" exists at 550 nm due to a lack of appropriate directly emitting LED materials. Accordingly, different LED types must be used. The yellow-

10. ERC Proof-of-Concept VeCoScan, Grant Agreement number 812583.

11. Giorgio Trumpy, Jon Y. Hardeberg, Sony George, Barbara Flueckiger, "A Multispectral Design for a New Generation of Film Scanners", *Proc. SPIE 11784, Optics for Arts, Architecture, and Archaeology VIII, 117840Z (8 July 2021)*, <https://doi.org/10.1117/12.2592655>.

Fig. 5. a and b. Comparison diffuse (top) vs. collimated (bottom) illumination. Film: *Lukas kleine Weltmaschine* (Ursula Helfer, 1993), hand-painted experimental film. Multispectral scan by Scan2Screen / Lutz Garmsen.

green gap can be covered by phosphor-converted green LEDs, but their spectral emission is too broad; a filter must be employed. Beyond their spectral properties, LEDs must possess the capability to support high current densities and powers. This is essential for generating sufficient brightness and enabling homogeneous illumination in both diffuse and direct modes, when integrated into a well-engineered optical system.

While most scanners exclusively use diffuse light due to its effectiveness in minimizing the visible effects of dust and scratches on the film, scanners for historical film stocks should ideally include the option to capture collimated light, i.e. directed illumination, to replicate the optical path of cinema projection. (Fig. 5 a and b) To these authors' knowledge, only the custom-built scanner made and operated by Cineric, Inc. in New York currently offers this feature. As a previous paper by the authors demonstrated,[12] the so-called chromatic Callier effect created by diffuse light also alters the colour appearance because it is wavelength dependent, especially in stocks containing silver or colour pigments, such as tinted and toned films, but also stencil-coloured and hand-coloured films. While it is true that directed illumination also captures the presence of scratches, the combination of diffuse and directed illumination allows for the creation of "scratch maps", which can help in reducing scratches in post-production.

For each individual multi-spectral scanner, the illumination unit's spectral response needs to be measured with a spectrophotometer. These measurements should be documented in the metadata to ensure accurate and efficient rendering both immediately and in the future as technologies and standards evolve, recognizing that while compliance is important, access to these measurements is fundamental for achieving accurate and reproducible rendering results.

12. Giorgio Trumpy, Barbara Flueckiger, "Chromatic Callier Effect and its Repercussions on the Digitization of Early Film Colors", *Journal of Imaging Science and Technology,* Vol. 63, No. 1, January 2019, pp. 10506-1–11.

MULTI-SPECTRAL SCANNING WORKFLOW: CALIBRATION AND RENDERING

Calibration, in the multi-spectral scanning workflow developed by the authors, consists of the following steps:

- Measuring the spectral distribution of the LEDs' emission, which will be used to define the weighting functions for the downsampling of the Colour Matching Functions. (Fig. 6)
- Determining the integration times to properly expose all the bands and normalize the spectral response.
- Capturing the white frame and the black frame for flat-fields to ensure that images express transmittance values and to level out the illumination across the capturing area.

In summary, the only factor that is adjusted in calibration is the exposure for each band, which is then combined with the flat-field for the rendering.

A user-friendly graphical user interface guides scanner operators through these steps, ensuring consistent adherence to scientific protocols, including the collection of metadata that describe the scanned film element and its provenance.

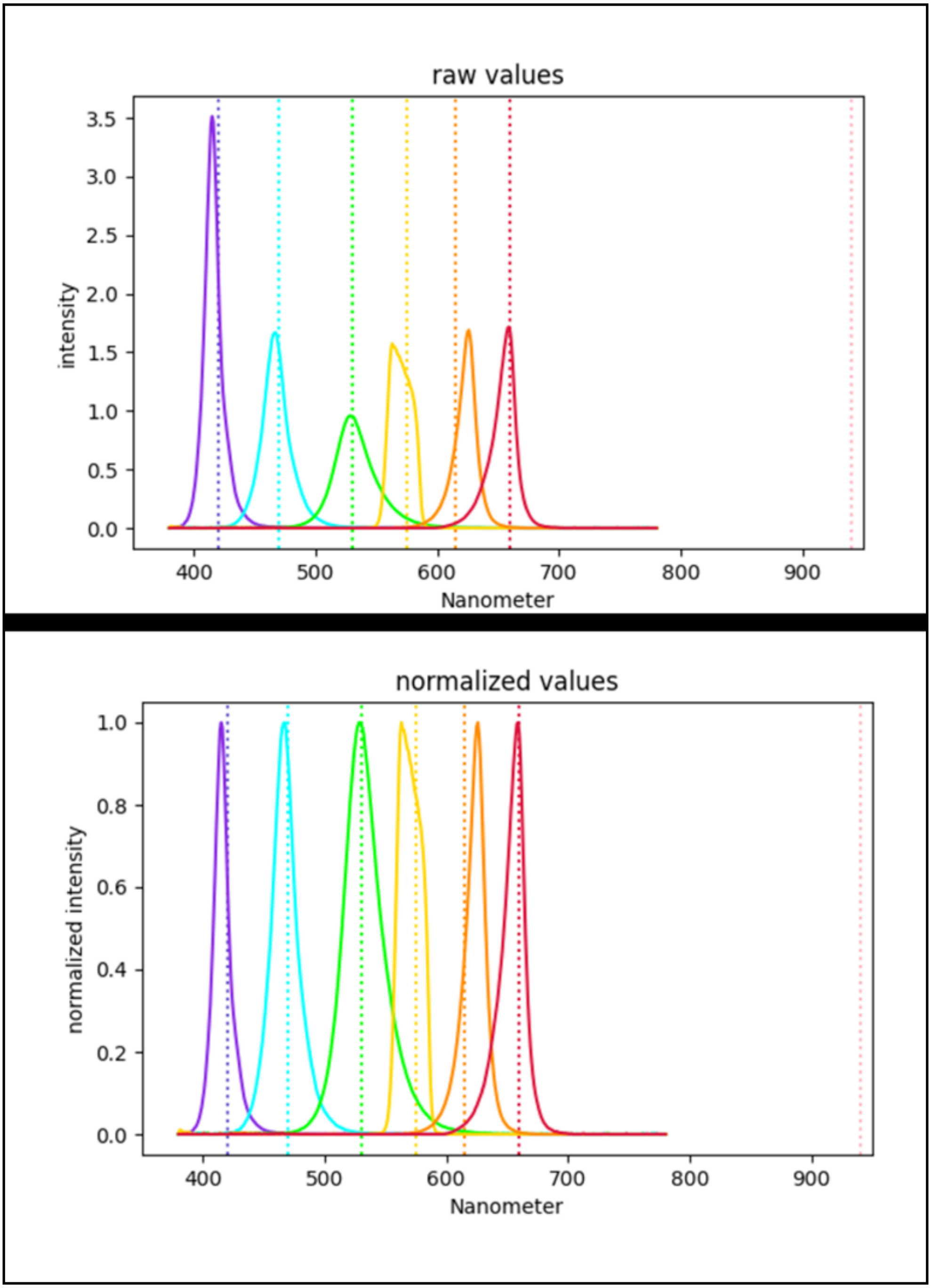


Fig. 6. Even distribution of the spectral bands is crucial for multi-spectral scanning. In calibration, the spectral response needs to be normalized.

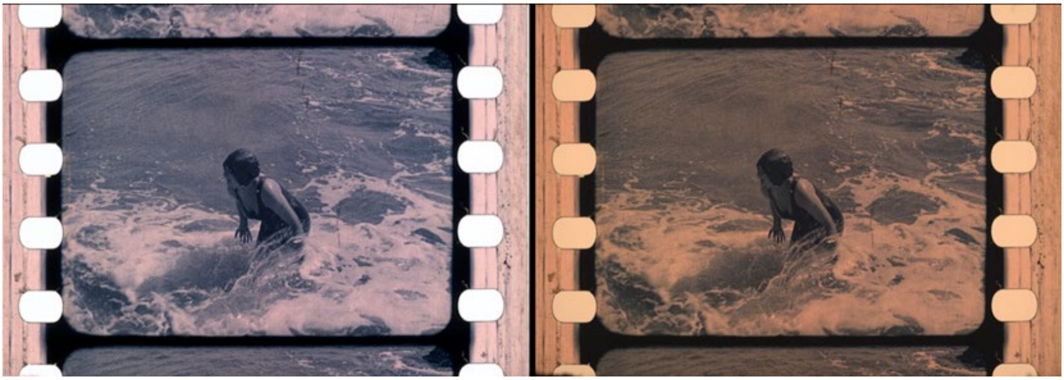


Fig. 7. Rendering is executed based on measured spectra of various cinema projections. Comparison xenon light (left) vs. carbon arc (right).

The visual *rendering* software, meanwhile, calculates the colours for the selected colour space (currently DCI-P3, Rec. 709, and Rec. 2020) based on measurements of cinema projection at the Lichtspiel / Kinemathek Bern and at David Pfluger's lab in Basel. (Fig. 7) These measurements were obtained by analysing projected light reflected from a Spectralon tile using a Qalif Spectro spectrometer. The following historical light sources were measured:

- Drummond Light or Limelight: Measured in an experimental setup.
- Zirconia Light: Measured in an experimental setup.
- Nernst Lamp: No data; emitter equivalent to the Zirconia light.
- Magnesium Light: Measured in an experimental setup.
- Carbon Arc Light: Measured in Hi and Low configurations using a Westrex Master 35mm projector, Century Projector Co., Ashcraft Manufacturing Co., NY.
- Incandescent Lamp: Siemens 2000 16mm projector with a Philips 500 W incandescent bulb.
- Halogen Lamp: Eiki SNT 16mm projector with an Osram 24V, 250 W halogen bulb with a cold mirror.
- Pulsed Super-High-Pressure Mercury Lamp (only used in the Norelco Shutterless Projector). The original light source is not available. Similar light source: High pressure mercury lamp lighting equipment. Measured with the protective glass removed using an Osram Powerstar HQI-TS 400 W/D Daylight bulb.
- Metal Halide Lamp: Beaulieu 708 EL Super8 projector with a DS8 Osram HTI upgrade. The light source was a 400W 55V Osram Halogen metal halide lamp HTI 400W/24.
- Xenon Arc Lamp: Eiki EX-3500 A 16mm projector with an Ushio 220V, 350W Xenon Short Arc Lamp.

The monochrome images captured for each film frame are used to calculate accurate colour values using standardized functions that describe the human visual system. This calculation is done considering the spectral power distributions (SPD) of historical light sources mentioned above.

Considering transmittance spectra with intervals of 5 nm or less, the CIE recommends computing tristimulus values using standard summations. In case of transmittance values with lower spectral resolution – such as those from our system – several deconvolution and interpolation methods have been proposed to reduce the spectral interval and improve the accuracy of the resulting colourimetric values.[13] With the outlook of using the multi-spectral imager for motion pictures, thus capturing tens of thousands of data cubes, it is convenient to streamline the computational pipeline.[14] Since motion picture scanning does not utilize colour targets, we implemented an alternative calculation method. This agile approach bypasses the need for interpolation transmittance spectra by using abridged spectra for the illuminant and observer functions.

Metadata are collected in a YAML file and completed with the text file documenting the spectral properties of the illumination unit.

LONG-TERM PERSPECTIVE AND CONCLUSION

The constant evolution of digital technologies, standards, and workflows fundamentally opposes the core tenets of long-term film preservation, a reality well-understood within the archival community.

One of the most pervasive concerns for the adoption of multi-spectral scanning is the larger amount of data generated in the process. While the stack of 7 to 16 monochrome images, uncompressed in native resolution, might sound daunting, it is in practice much easier to handle. Once renderings are complete, raw scans can be stored cost-effectively offline in cold storage, such as LTO tapes, for long-term preservation. In a test, a luma-only TIFF sequence created by the scanner could be compressed successfully into a single MKV-wrapped FFV1 file, achieving a compression ratio of approximately 1.4:1.

The comprehensive capture of the full range of colours, all stored in monochrome image files, offers optimized elements for long-term preservation because the colour information is scientifically accurate and therefore independent of current standards or devices. Consequently, the monochrome images can be retrieved for future re-renderings that comply with new standards and workflows, eliminating the need to rescan the film and potentially the need for film-outs, which are cost, labour, and energy intensive.

A multi-spectral approach to film scanning addresses critical limitations in the digitization of historical colour films up until now. By capturing the full spectral range of diverse film stocks and colour processes, this method ensures fidelity to the original materials and compliance with preservation ethics. As digital technologies evolve, multi-spectral data provides a robust foundation for sustaining cultural heritage in the digital domain.

13. R.W.G. Hunt, M.R. Pointer, *Measuring Colour*, Fourth Edition. Chichester: John Wiley & Sons, Ltd., 2011, pp. 197-217 (chapter "Precision and Accuracy in Colorimetry"); A. Mansouri, F.S. Marzani, P. Gouton, "Neural Networks in Two Cascade Algorithms for Spectral Reflectance Reconstruction", *IEEE International Conference on Image Processing 2005*, Genova, Italy, 2005, pp. II–718.
14. Benjamin A. Darling, James A. Ferwerda, Roy S. Berns, Tongbo Chen, "Real-Time Multispectral Rendering with Complex Illumination", *Proc. IS&T 19th Color and Imaging Conf.*, 2011, pp. 345–351.

fr

Cet article s'intéresse aux défis et aux progrès dans la numérisation des films historiques en couleur, et se focalise sur les limites des technologies actuelles en la matière, plaidant pour une approche de numérisation multispectrale plus rigoureuse et fondée sur des bases scientifiques. Les auteurs soulignent le manque de transparence et de documentation concernant les principes optiques régissant la plupart des scanners commerciaux, ce qui affecte la précision de la reproduction des couleurs lors de la numérisation. Malgré des recherches d'importance dans le domaine de la restauration des films, les scanners ne parviennent généralement pas à capturer l'intégralité des caractéristiques spectrales des films historiques, en particulier ceux utilisant des procédés colorimétriques uniques autres que les films chromogéniques récents.

Les auteurs proposent une méthode de balayage multi-spectrale qui capture une gamme plus large de longueurs d'onde régulièrement espacées sur l'ensemble du spectre visible afin de mieux représenter les couleurs variées que l'on trouve dans les films historiques. Cette approche garantirait une conservation numérique plus fidèle et précise, en évitant les ajustements de colorimétrie subjectifs souvent requis par les *workflows* actuels.

L'article souligne également l'importance de la documentation des caractéristiques spectrales des films, en préconisant un *workflow* minimisant la subjectivité humaine et donnant la priorité à des résultats objectifs et reproductibles. Cela permettrait de respecter l'éthique de la restauration, dont la transparence et la réversibilité, tout en garantissant une adaptabilité à long terme à des normes numériques en constante évolution. Les auteurs décrivent les défis techniques posés par la numérisation multispectrale, notamment la nécessité de technologies LED spécifiques et l'utilisation d'une lumière collimatée pour reproduire le chemin optique de la projection cinématographique. L'étalonnage est basé sur la mesure spectrale de l'unité d'éclairage.

Le rendu calcule des valeurs de couleur précises à l'aide de fonctions normalisées décrivant le système visuel humain. Ce calcul est effectué en tenant compte des distributions de puissance spectrale (SPD) des sources de lumière historiques, ce qui permet un nouveau rendu sans nouvelle numérisation. Tout en reconnaissant que le balayage multispectral engendre une augmentation de la quantité de données générée, les auteurs affirment qu'il s'agit d'une solution robuste et de long terme pour sauvegarder les films historiques de façon authentique. Au bout du compte, cette méthode est une réponse aux limites des méthodes actuelles de numérisation, et représente une approche scientifiquement précise et durable de la préservation du patrimoine culturel.

es

Este artículo analiza los retos y avances en la digitalización de películas históricas en color, centrándose en las limitaciones de las tecnologías de escaneo actuales y abogando por un enfoque de escaneo multiespectral más riguroso y con una base científica más sólida. Los autores destacan la falta de transparencia y documentación sobre los principios ópticos que subyacen en la mayoría de los escáneres comerciales, lo que afecta a la precisión de la reproducción del color durante la digitalización. A pesar de la importante investigación en restauración de películas, los escáneres no suelen capturar todas las características espectrales de las películas históricas, especialmente aquellas con procesos de color únicos distintos de las películas cromogénicas recientes.

Los autores proponen un método de escaneo multiespectral que captura una gama más amplia de longitudes de onda espaciadas uniformemente en todo el espectro visible para representar mejor los variados colores que se encuentran en las películas históricas. Este enfoque garantizaría una conservación digital más precisa y fiel, evitando los ajustes subjetivos de color que a menudo requieren los flujos de trabajo actuales.

El documento hace hincapié en la importancia de documentar las características espectrales de las películas, abogando por un flujo de trabajo que minimice el juicio humano y dé prioridad a resultados objetivos y reproducibles. Esto se alinearía con la ética de la restauración, como la transparencia y la reversibilidad, al tiempo que garantizaría la adaptabilidad a largo plazo a los estándares digitales en evolución. Los autores describen los desafíos técnicos del escaneo multiespectral, incluida la necesidad de tecnologías LED específicas y el uso de luz colimada para replicar la trayectoria óptica de la proyección cinematográfica. La calibración se basa en la medición espectral de la unidad de iluminación.

El renderizado calcula valores de color precisos utilizando funciones estandarizadas que describen el sistema visual humano. Este cálculo se realiza teniendo en cuenta las distribuciones de potencia espectral (SPD) de las fuentes de luz históricas, lo que permite volver a renderizar en el futuro sin necesidad de volver a escanear. Aunque reconocen el aumento de datos generados por el escaneo multiespectral, los autores sostienen que proporciona una solución sólida a largo plazo para salvaguardar la autenticidad de las películas históricas. En última instancia, este método aborda las limitaciones de las prácticas actuales de digitalización, ofreciendo un enfoque científicamente preciso y sostenible para preservar el patrimonio cultural.