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Originally published at:
Trumpy, G., Hardeberg, J. Y., George, S., & Flueckiger, B. (2021). Multispectral capture of film colors with LED. In B. Cattaneo, M. Picollo, F. Cherubini, & V. Marchiafava (Eds.), Colour photography and film : sharing knowledge of analysis, preservation, conservation, migration of analogue and digital materials – Conference proceedings (pp. 195–198). Gruppo del Colore – Associazione Italiana Colore. https://www.gruppodelcolore.org/portfolio-articoli/florence-2021/?lang=en

# Colour Photography and Film: Sharing knowledge of analysis, preservation, conservation, migration of analogue and digital materials – Conference Proceedings

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ISBN 978-88-99513-14-6


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Published in the month of July 2021

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*March 29-30, 2021*

*Organised by Gruppo del Colore – Associazione Italiana Colore*

*Under the patronage of*
*Opificio delle Pietre Dure*
*and*
*Institute of Applied Physics "Nello Carrara" of the Italian Research Council (IFAC-CNR)*

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# Multispectral capture of film colors with LEDs

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**Keywords:** Multispectral imaging, photographic film, film digitization, film projection.

**Limitations of conventional film scanners**

The digital reproduction of a historical movie should resemble as much as possible the analog film projection at the time of the movie release. In reality, the professional film scanners that are widely used nowadays in the digitization of archival films were primarily conceived to excel in the *Digital Intermediate* workflow of contemporary film productions (Flueckiger et al., 2018). Their optical configuration is thus optimized for film negative stock of recent production and is not compatible with the vast variety of film processes that constitute the holdings of public archives and private film collections.

The technical limitation of the digital image capture carried out by conventional film scanners is twofold: on the one hand, the limitation is associated with the diffuse illumination of the film, and on the other hand, with the spectral sensitivities of the RGB capture.

A serious limitation of all conventional film scanners is their illumination method that does not properly reflect the conditions of film projection. To guarantee a sufficient brightness on the screen of cinema theaters, film projectors employ parabolic mirrors or condensers that direct the light into the lens that creates the image of the photographic emulsion on the screen (*condensed* illumination). All most popular film scanners capture photographic images illuminating the film with an opal glass or an integrating sphere to achieve a *diffuse* illumination. This type of 'soft' illumination has the important advantage of attenuating the dark marks of dust and scratches on the film (Mead, 2006), but it does not conform with the way film is illuminated during film projection. Tinted and toned films and other early film colors produce quite different appearances in diffuse and condensed illumination: the condensed illumination creates an image with deeper darks and more evident grain, while the diffuse illumination creates an image with lower global and local contrast (Gregory, 1927; Streiffert, 1947). If the diffuse/condensed discrepancy is not properly taken into consideration, early film colors risk to be improperly digitized and their digital version will not match the appearance of the original analog projection (Trumpy and Flueckiger, 2019).

Conventional film scanners can be ascribed to two categories according to the spectral width of their RGB bands. On the one hand, there are spectral bands that do not overlap, aiming at the absorption peaks of typical dyes of modern chromogenic films (cyan, magenta and yellow); these *narrow bands* are conceived to extract information about the concentrations of the film dyes and enhance the resulting digital color (Gschwind, Frey and Rosenthaler, 1995). On the other hand, there are spectral bands that largely overlap; these *broad bands* are conceived to resemble the human visual system and aim at color rendition in accordance with human perception. These fixed categories represent a strong limitation for the digitization of film colors, as some types of film should be digitized aiming at the maximum digital color information, while the color accuracy is most important for other types (Trumpy and Flueckiger, 2015). For example, it is preferable to digitize a faded chromogenic film with narrow bands, as this offers a more effective digital restoration. However, the enhanced colors produced by the narrow bands become excessive whenever a well-preserved projection print has to be reproduced (Fossati, 2009).

**A new multispectral imaging system**

To overcome the limitations reported in the introduction, a multispectral imaging system was designed and built, serving as a prototype of a new film scanner that can produce the most suitable digital image for all types of historical film. The film (Fig. 1-G) is illuminated with a condensed beam that resembles illumination of film projection. The possibility to insert a light diffusing slab close to the film (Fig. 1-F) allows to switch between condensed and diffuse illumination, thus benefiting from a true-to-projection color rendering, as well as from attenuated marks of dust and scratches. According to the type of film stock and its physical conditions, the scanner operator has the possibility to choose between the two types of illumination. The film scanner also allows to capture each film frame in both diffuse and condensed illumination, thus opening the possibility for image processing procedures that combine the advantages of both illumination conditions.

For each photographic image, the imaging system captures the spectral images sequentially on an area array sensor. The illumination is provided by a set of ten light-emitting diodes, whose emissions determine the spectral bands of the imaging system. In order to let all LEDs homogeneously expose the field-of-view with a condensed beam, it was necessary to efficiently bring their light to a common area where the ray bundle of all the LEDs has a similar geometry. To achieve this condition without moving parts, a custom-made integrating sphere has been 3D printed in resin (Figure 1-A), having a 12 cm diameter and whose interior has been sprayed with a nearly-Lambertian reflectance coating. The LEDs (Fig. 1-C and -B) shine light inside the sphere through the entrance ports, and after being scattered, the light comes out from the 2 cm diameter exit port at the top of the integrating sphere. The light coming out from the sphere is collected by a first condensing lens (Fig. 1-D) with a numerical aperture of 0.76 that allows to minimize the dispersed light. The second condenser (Fig. 1-E) has a diameter of 75 mm and a focal length of 200 mm. The system is configured in such way that the beam is slightly diverging between the two condensing lenses—so to increase the illuminated area—and the image of the sphere's exit port is created approximately where the aperture of the imaging lens is positioned (Fig. 1-I).

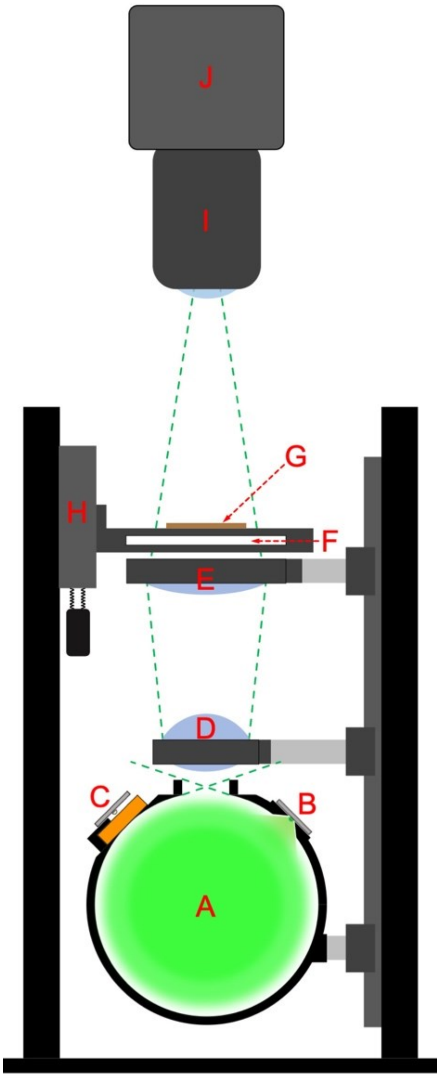


Fig. 1 - Diagram depicting the integrating sphere (A), one of the LEDs that directly shines into the sphere (B) and one of the LEDs that shines through an interference filter (C). The first (D) and the second condensing lens (E). The sample holder with the light diffusing slab (F), the focusing stage (H) and the film sample (G). The imaging lens (I) and the monochrome camera (J).

The camera (Fig. 1-J) has a back-illuminated full-frame CMOS monochrome sensor with 61 megapixels, and it is equipped with a 100 mm macro lens. The field-of-view necessary to fully cover—perforation area included—the 135 still photography format is 54 × 36 mm. The resulting resolution is 4500 ppi, which is enough to capture the relevant detail of a fine-grain photographic image on film.

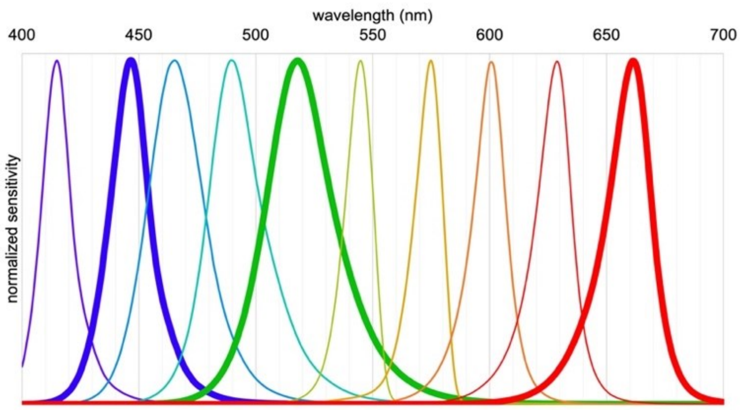


Fig. 2 - The normalized spectral bands of the multispectral imaging system. The thick curves indicate the RGB narrow bands used by conventional film scanners.

In the presented imaging system, the multispectral capture comprises ten spectral bands that are evenly distributed in the visible spectral range and have limited overlap (Fig. 2). Since no LED can be found on the market with a narrow emission peaking between 530 and 590 nm, two broad-band LEDs shine through two different interference filters (as depicted by "C" in the diagram of Fig. 1). Three bands of the final set reported in Fig. 2 (the thicker curves) correspond to the conventional red, green and blue narrow bands described in the previous section. This allows to either enhance the digital color information by selecting the red, green and blue bands only, or to make use of all the spectral bands and obtain the most accurate colors. This flexibility allows to properly digitize all types of film colors: well-preserved projection prints as well as faded dyes, non-standard colors of early cinema as well as camera negatives and other intermediate film elements.

**Image capture and processing**

A preliminary calibration procedure is necessary before capturing the film every time the system has been reconfigured (i.e., repositioned camera or illumination system). For each LED, after identifying the integration time that makes the best use of the linear dynamic range of the sensor, two images of the empty gate—without film—are captured and stored: the "*white*" image with the LED on and the "*dark*" image with the LED off. The film frame is captured with the same integration times, and a *flat-field* operation computes the film's transmittance values that are expressed with 16 bits and stored as data-cube file (ENVI Header Files [Internet] 2020).

The multispectral system was tested on a set of slides from the holdings of the Art Institute of Chicago. The image content and transmittance values are reported in Fig. 3 for one of the slides. The color image is the result of colorimetric calculations performed on the data-cube file (Schanda, 2007).


Fig. 3 - An edge-to-edge multispectral capture of a slide with the LED-based system (left). Bottom-right: Image detail of the car roof. Top-right: Transmittance values corresponding to the yellow skirt of doll on the left and to the red turban of the doll on the right. Courtesy of the Art Institute of Chicago.

**Conclusion**

A multispectral method for image capture of film could greatly improve the digital cinematic experience and its fidelity with the supposed visual experience in the cinema theaters of the past. The urge of such innovation has been demonstrated in the framework of the ERC Advanced Grant *FilmColors* at the University of Zurich by analyzing the multitude of historical color film processes, investigating their optical properties, developing and testing a multispectral scanner prototype, and gathering the feedback of experts during simultaneous analog/digital projections (Op den Kamp, 2020). In the late 2020 the optical design of the future multispectral film scanner and the computational pipeline of the captured images have been further elaborated at the Norwegian Colour and Visual Computing Laboratory. The collaboration resulted in a new imaging system in transmission mode that efficiently captures multispectral images of photographic film and offers inspiration for the future development of a new generation of film scanners.

**Acknowledgements**

The construction of the multispectral imaging system was funded by the project IMATCH from the Norwegian Regional Research Fund (RFF Innlandet) – grant No 298914. Tor Erik Nicolaisen and Monika Skaug Bakkehaug gave support for the 3D modeling and printing, Luvin Munish Ragoo for the electronics, Binu Melit Devassy and Ronny Xavier Velastegui Sandoval for the software. Jean Baptiste Thomas and Julius Muschaweck gave fundamental advice for the optical design. Special thanks go to Sylvie Pénichon who provided the slides for the experiments. The fundamental concept that inspired the work have been developed under the European Union's Horizon 2020 research and innovation programme – grant agreement No 670446 *FilmColors*.

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