Long-term Preservation of Digital Images on Color Microfilm

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Abstract

For the long-term archiving of digital images, a laser film recorder is being developed. It images color microphotographs on unperforated 35mm silver-dye bleach material in high resolution (pixel-size 3 micrometers).

The goal of the archiving process is to achieve a precise colorimetric reproduction. However, color gamut and dynamic range of the photo-material used is relatively small. Consequently, an "archival colorimetric transform" has been developed. Its purpose is to record a maximum of the original's information on the microfilm, using adequate gamut compression based on sensitometric measurements of the photographic material.

A modified IT8 scanner target is also recorded on the microfilm as a reference for the reconstruction of the archived color information.

Introduction: Long-Term Archiving

No matter how carefully the original analog data is stored, it is doomed to deteriorate. The degradation may occur sooner or later, the signs of decay be more or less visible, but this process eventually leads to a total loss of the information recorded on the analog medium. This has become a particular concern of the art preservation community. In addition to natural decay, accidental destruction constitutes another threat to art collections, as recent events have shown (e.g. 2004: inferno destroying the Herzogin-Anna-Amalia Library in Weimar, Germany, 2002: floods in Prague, Czech Republic). No collection is ever safe and it should be considered part of our duty to preserve today's cultural heritage for future generations.

Making duplicates of art works is the only way to avoid the total loss of invaluable unique oeuvres. As opposed to mere analog reproduction, digitization of art collections offers several advantages, including fast access, transfer and exchange of digital data through communication networks, convenient reproduction by printing, etc. However, the medium carrying the information remains analog and therefore affected by the problems of a limited lifetime, as described above. Furthermore, archiving digital data always requires the preservation of the specific data formats and hardware to read the storage medium. Without repetitive migrations of the information to new formats and media, the obsolescence problem remains.

This paper presents a solution for the long-term archiving of high-resolution digital duplicates (digital masters). The aim of the archiving process is to be able to retrieve the entire information of the original, including color and spatial resolution. For this purpose, a microfilm recorder has been developed,[1] that allows the recording of images of a size up to 10000 × 15000 pixels, on color microfilm. The color issue is managed by using an "archival colorimetric transform" as described below.

The proposed method offers several advantages compared to digital archiving:

- "Eternal storage", thanks to the extreme stability of color microfilm.
- No costly migration procedures, which are often neglected in times of low budgets.
- Independence of specific format, as the digital image is recorded in an analog way.
- No special hardware (computer) required to "see" what is recorded, as the image can be viewed with bare eyes, as opposed to bits and bytes in a digital file.
- No virus attacks or manipulations of the data are possible.

Archival Medium: Color Microfilm

To attain long-term preservation of data, the analog data carrier must be extremely stable, both physically and chemically. For this particular application, it should additionally be adapted to hold high-resolution color images, as digital image taking devices can currently deliver. The Ilfochrome® Micrographic film from Ilford,[2] a high-resolution, direct-positive color film based on silver-dye bleach technology meets each of these requirements. It is a very low speed material requiring high intensity light exposure, which makes it sub-optimal for direct recording of highly sensitive originals. However, when recording from digital data with a high intensity laser film recorder, as in the case here, this drawback is irrelevant.

Studies have shown[3,4,7] that the Ilfochrome® Micrographic film is extremely durable, with a life expectancy of over 500 years. This stability means that the fading of the color dyes remains almost imperceptible. Furthermore, its resolving power of 325 lp/mm makes it an ideal information carrier for high-resolution images.

Technology: Laser Microfilm Recorder

As part of a project establishing long-term archiving, the Fraunhofer IPM is developing a novel laser film recorder.[1] This new technology, the so-called "ArchiveLaser", is working with a red, a green and a blue laser. The individual laser beams are modulated according to the image information using acousto-optic modulators and are finally combined through a special optical device. When recording the data on microfilm, the combined beam is then focused to a pixel size of 3 µm, which enables one to record 160 lp/mm. The data can be recorded on 35 mm b/w or color preservation microfilm within frames of 32 × 45 mm.

Using this technology, the ArchiveLaser is able to precisely produce true colors and grayscales, as well as finest details and high contrast with a superior productivity. Data can be recorded as an analog image and/or a digital code. Furthermore, the costs per image or per gigabyte of data are considerably lower than with any other existing long-term storage technology.

The reliable engineering and solid construction of the ArchiveLaser system is based on a proven and very successful technology developed for the cine film recording industry – with up to 150 running systems worldwide – and has been awarded the "Scientific and Engineering Award" from the Academy of Motion Picture Arts & Sciences in 2002.

Specifications of ArchiveLaser

Frame size	32 x 45 mm (on 35mm Film)
Pixel size	3 µm (160 line pairs/mm)
Pixels per frame	10,666 x 15,000 pixel (159.9 million)
Film material	b/w or color microfilm (Ilford, Kodak, etc.)
Exposure time	40 sec. per frame
Film transport	magazines of up to 600 m (13,000 frames)
Diminution factor	34 (i.e. 1 DIN A0 image per frame)
Storage capacity	images: 16 DIN A4 images per frame; digital data: 1 Gigabyte per 25 cm film
Productivity	approx. 100m per day

In addition to the image itself, metadata is also recorded on the film in textual form along the image border. This could be descriptive information about the image and its content as well as technical metadata such as film batch number or date. The metadata not only ensures a quick reconstruction of the original data structure, but also facilitates the search for a specific document or image. Furthermore, a continuous control color strip is also recorded below the images to allow for the automatic quality control of the recording process.

Archival Colorimetric Transform

The goal of the archiving process, from a color reproduction point of view, is to be able to reproduce the exact colors of the original. However, due to limitations of microfilm (see below), it is not possible to achieve a colorimetric reproduction on this medium. In order not to lose color information by clipping (in the highlights, shadows and saturated colors), the original color space must be compressed before recording the images. To be able to recover the true colors of the originals at the re-digitization step, it is necessary to record on the microfilm, along with the archived images, a set of well-defined reference colors describing the input color space of the images and the textual description (e.g. in the CIELab color space) of each reference color.

Gamut Compression

From the perspective of a conventional imaging workflow, the best solution for recording color images on microfilm would be to characterize the film and the recorder using the ICC Profile approach. However, this method would not be appropriate for the application in question, as the film is used as an information carrier predominantly. It is not the main purpose to obtain pleasant or colorimetrically correct images on the film, but to preserve the color information throughout the entire archiving chain. The final result after re-digitization is most important.

Images to be recorded on microfilm may come in various RGB color spaces, each defined by their relation to the CIELab color space. Every single one covers a slightly different portion of the CIELab space, but the latter is never fully exploited. Therefore, the color compression algorithm is optimized for a particular RGB color space, instead of compressing the entire CIELab color space onto the microfilm's color gamut. This way, the usable optical density range of the film is exploited to an optimum. As a result, it is possible to reach a high number of quantization steps, while at the same time taking into account the sensitometric characteristics of the film material and the modifications generated by film aging.

Photographic material is not an ideal quantitative recording medium, as it exhibits various non-linearities. One is due to the non-linearity of the characteristic curve. The linear part of the characteristic curve, which can be used for quantitative recording, is quite small and therefore the usable density range of the microfilm remains well below that of the originals.

Another source of non-linearities in color–film is due to inter-image effects.[8] The exposure of a single layer in a photographic color material does not only determine the amount of its own appropriate dye (yellow, magenta, cyan), but also influences the amount of dyes being processed in the other two layers. This phenomenon is known as the inter-image effect (IIE) and can either improve or impair the reproduction of colors. A more saturated reproduction of colors is achieved if the exposure of a layer X lowers the amount of dye in another layer Y. The dye in layer Y has to absorb mainly in the spectral region of the side absorption of dye X. This kind of inter-image effect is intentionally introduced into many chromogenic color materials and works by the mechanisms of so called DIR (Developer Inhibitor Release) couplers. In silver-dye bleach materials, as used for the proposed Ilford Micrographic film, the inter-image effects are very low due to the specific photographic mechanism and can be neglected.

Consequently, the gamut of the input RGB color space must be compressed in order to reach the best compromise between:

- Using the steep part of the characteristic curve only (avoiding the toe and shoulder)
- Allowing for headroom in case of film fading
- Creating visually acceptable images.

Color Reference Chart

The gamut compression is such that only the steep part of the characteristic curve of the film is used. This facilitates the color management in the re-digitization process, where only simple mathematical models are needed to describe the relation between the colors on the film and their CIELab equivalent. As opposed to the color characterization of a printer, which is highly non-linear, the models are built on only a small number of reference color fields.

As set of reference colors, we use a modified IT8-like color chart, which has been adapted to the specific purposes of our application. This chart was chosen in view of the fact that the format is widely used for the calibration of scanners and color characterization software is readily available to handle it. Any other format would also be possible, but would involve the cost of writing new processing software. A digital image of the color target is built and saved in the same RGB color space as the original images. It then undergoes the same color transformation as the other images before being recorded on the film.

The IT8 color transmission calibration target was defined[5,6] to describe the color properties of the medium on which it is recorded. The color fields are divided in three distinctive areas.

- The colors on the left part of the chart (columns 1 through 12) are independent of the medium. They are distributed among the hue angles of the CIELab color space and their chroma and lightness are such that any usual color film can represent them. For these color fields, it is straightforward to compute the corresponding RGB values in the adequate color space.
- The fields in columns 13 to 19 are color- and gray-scales specific to the color gamut of the medium on which the target is to be recorded. In our case however, we do not intend to describe the color gamut of the microfilm, but the actual gamut of the input RGB space of the images. This is necessary, as the colors are transformed (gamut compression) before being recorded on the microfilm. Therefore, color scales are built following the outer boundaries of the RGB gamut and computing the corresponding CIELab values to be saved in the textual reference file.
- The last three columns (20 to 22) are left open for the manufacturer of the color target. We use this space to write the textual description of the color fields (CIELab values) in standard calibration file format (see Ref. [5], annex C). This information is used for the color management during the re-digitization process.

Any RGB color space can be used for the input images. However, it is advised for reproduction purposes to use an RGB space with a large color gamut, capable of holding most of the color information of the originals. The ECI RGB color space[9] seems like a good compromise. It covers a large part of the CIELab color space and, opposed to other large gamut RGB spaces, it does not contain “imaginary” colors (e.g. Kodak ProPhoto RGB). Note that it is important to work with 16-bit precision when using large gamut color spaces to avoid color quantization errors.

Re-digitization of Images

As the digital images are stored in an analog way on the film, little more than a light source and a magnifying glass are needed to look at them. To retrieve the digital version of the images, a microfilm scanner is used. In this process, the reference IT8-like color target is scanned as well. Next, the text file describing the color fields of the characterization target in the CIELab color space can be retrieved using OCR or, in the worst case, a manual copy.

It is now possible to compute an ICC Color Profile using conventional color characterization software. The film and the scanner are characterized as a single entity based on the scanned color target and its reference file. Applying the ICC Profile to any scanned color images closes the archiving loop and restores the colors of the original digital images.

Conclusion

Combining modern film recording technology and microfilm sensitometry it has become possible to archive digital color images in extremely high spatial resolution and with high colorimetric quality. Thanks to the stability of color microfilm, this image archive is guaranteed to last over 500 years. Even if the microfilm were to fade, the colors of the originals could be retrieved with high colorimetric precision using the recorded IT8-like targets for the color characterization.

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Author Biographies

Cédric Normand, born 1977, studied Information and Communication Systems at the Swiss Federal Institute of Technology in Lausanne and graduated in 2003 with a Masters degree, specializing in Color Imaging. Since 2004 he has been a scientific collaborator in the "Imaging and Media Lab" at the University of Basel, working towards a Ph.D. in the field of color reproduction.

Rudolf Gschwind, born 1949, studied Chemistry at the University of Basel, and in 1979 obtained a Ph.D. in Physical Chemistry in the field of Photochemistry. During his studies he became involved in scientific photography. Since 1980 he has been Head of Department at the “Scientific Photography Lab” at the University of Basel, now known as the “Image and Media Lab”. In 1985 he spent a year’s sabbatical carrying out *industrial research at IlfordAG, Fribourg/Marly (Electronic Imaging) and between 1989-1999 he did additional research and teaching at the Swiss Federal Institute (Zürich), Photography Group in the Institute of Physical Chemistry. During this period he also developed new methods for the digital reconstruction of faded color photographs. His main research topics are image processing and analysis, color photography, color imaging, and preservation of audio-visual cultural heritage.*

W. J. Riedel received his diploma in Physics in 1972 from the J. W. Goethe University of Frankfurt. He worked eight years with the R&D division for diode lasers of AEG. In 1980 he joined Fraunhofer IPM. He is an expert in the areas of spectroscopy and laser recording and in 2002 was granted the "Scientific and Engineering Award" from the Academy of Motion Picture Arts & Sciences for the design and development of the worldwide leading cine laser recording system.