RGB laser COM system for recording digital image data on color microfilm offers new perspectives for long-term archiving

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Abstract

Part of the huge amount of digital data generated these days has to be archived for decades due to legal reasons or has to be preserved for centuries and for future generations. Because the readability and lifetime of electronic storage media is rather limited, electronic digital storage systems have to be reformatted or copied on new media every five to ten years. In clear contrast, microfilm has a life expectancy of several hundred years and its content remains human readable. While data recording on b&w microfilm has been widely established for long-term archiving, recording on color microfilm has been fairly limited in the past mainly due to the lack of productive and easy-to-use equipment resulting in prohibitive cost levels.

An RGB laser COM system - called Eternity - has been developed by Pro Archive to provide users a unique tool for high-resolution and high-speed recording of image data on color microfilm. The Eternity recorder is based on red, green and blue lasers at its core. These lasers produce color images onto either 35 mm or 105 mm wide color microfilm. The Eternity uses an internal drum configuration where the focused laser beam hits the film material in normal incidence all over the exposure area. This ensures high resolution and consistent color quality without the compromising effects of classical camera- and display-based photographic exposure systems. Thanks to a recording density of 7,580 dpi one single color microfiche offers a storage capacity of up to 3.65 GB of digital image data or of about 100 original A4 color pages scanned at 300 dpi. A 60 m microfilm cassette enables recording of 400 microfiches without reload, hence providing autonomous recording of about 40,000 A4 color pages within 48 hours of operation.

The Eternity laser recorder enables long-term retention of image data on color microfilm that outperforms existing methods with respect to safety, longevity and total cost of ownership.

The Challenge – Safe and Affordable Data Retention

Part of the huge amount of digital data generated every day has to be archived for decades due to legal reasons or has to be preserved for centuries and for future generations. Because the readability and lifetime of electronic storage media is endangered due to technical obsolescence (the digital cliff), electronic digital storage systems have to be reformatted and/or copied onto new media every five to ten years. Consequently, digital data retention and archival storage lead to high recurring costs.

The National Archives and Records Administration's Electronic Access Project (NARA-EAP) provided interesting cost estimates for image scanning and preservation [1]. NARA-EAP master files averaged 10 MB and cost $7.60 to scan; EAP oversized documents averaged 70 MB and cost $20 to scan; commercial photo CD images average 18 MB and cost $2 to scan. Hence, the initial cost of scanned image files was $110/GB to $760/GB. The cost estimate for the preservation of digital image files for the first 10 years (one copy of master file, copying to new storage disks twice over 10 years, and converting file format once over 10 years) worked out to $1.70 to $4.70 per image, corresponding to costs of at least $17/GB/year.

The Harvard University Art Museum's photography studio made a complete transition from film to digital several years ago, digitizing approximately 1,200 vintage 4" x 5" negatives at 2,000 dpi 24-bit color [2]. Average file size for the uncompressed Tiff images was 229 MB. When deposited to the Online Computer Library Center (OCLC) digital archive at the $15/GB/year discount rate, the costs are $3.35/year per photograph versus the $0.017/year per transparency price for managed storage deposit in the film vault before (which would be equivalent to costs of $0.07/GB/year).

The National Archives in Stockholm (NAS) have invested in a data storage system in 2003, with a tape cassette robot for long-term storage of digital records, a capacity when fully used of 200 TB, and set up to be able to expand with 40TB/year [3]. The cost estimate for the system and for operating it on this scale leads to TCO of about $3/GB/year.

The cost levels of both disk and tape storage based on operational experience at the San Diego Supercomputer Center (SDSC) running a large-scale 25 PB storage infrastructure have been published recently [4]. One disk copy at SDSC would be $1.50/GB/year while one tape copy would be $0.50/GB/year. Of the total cost of ownership (TCO) for disk storage the media cost accounts for 36%. Hence cost reductions due to ever decreasing disk prices will not reduce the TCO by more than one third.

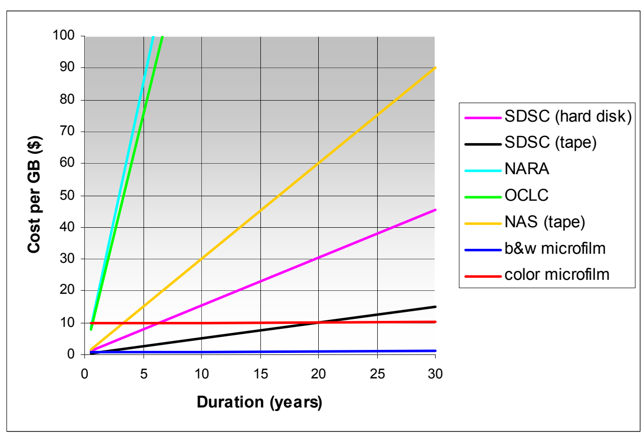

***Figure 1**. Total cost of ownership (TCO) for data retention on digital media as well as on microfilm.*

Motivation – Data Preservation beyond Digital

All of the above mentioned reports on the cost levels per GB per year for digital data retention (visualized in Fig. 1) lead to the following conclusions:

- Institutions will only be able to justify the retention of digital image data that is frequently used , e.g. accessed online;
- Institutions will need to perform a cost-benefit analysis to determine how much digital image data is provided online;
- Image data storage on microfilm offers lower risk at substantially lower TCO for long-term preservation;
- Hybrid approaches, using each technology to its best advantage, are likely to continue to be the most viable.

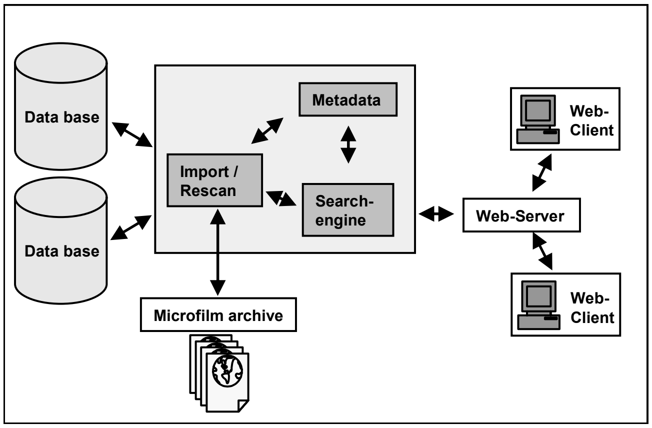

Figure 2*. Hybrid approaches, using digital technology and analog microfilm to its best advantage, are likely to continue to be the most viable and affordable image data retention concept.*

Color Microfilm – A Viable Archival Medium

It has been shown that Ilfochrome micrographic film with a resolving power of 365 lp/mm is the medium of choice for color image recording and long-term preservation [5-7]. Although its rather low sensitivity of 0.2 to 0.5 ASA was challenging classical camera- and display-based photographic exposure devices, it causes no limitations for image recording with laser systems.

In a study sponsored by The Getty Grant Program on the suitability of color microfilm for preservation [8], the conclusions were:

- Color microfilming is a viable preservation method. Even at room temperature, it is possible to preserve master color microform images as long as 100 years;
- At room temperature and moderate RH conditions, Ilfochrome (formerly Cibachrome) silver dye bleach films exhibit superior permanence to chromogenic microfilms;
- Ilfochrome emulsions can be expected to remain in usable condition for at least 200 years at room temperature and moderate RH conditions.

As a result, color microfilm is a safe and migration-free archival medium for hundreds of years. While data recording on b&w microfilm has been widely established for archiving, recording on color microfilm has been fairly limited in the past mainly due to the lack of productive and easy-to-use equipment resulting in prohibitive cost levels.

Solution - RGB Laser COM

The Eternity RGB laser COM system was designed to bridge the gap between digital and analog technologies combining the advantages of long-term preservation microfilm and of digital records management. Additionally, the Eternity provides a new cost level for image data recording on color microfilm: $10/GB or $0.10 for a 10 MB color image file which is considerably lower than for any other existing technology.

Workflow

The use of color microfilm for data preservation beyond digital storage can be embedded into an archival concept as illustrated in Fig. 2. The digitization of cultural heritage or any other originals with high resolution scanners is already established at many organizations. The digital image data from digitization projects or from existing data-bases can be organized and prepared on data management and/or digital library systems. All kinds of information can easily be added as metadata. After preparation, the digital data including metadata is directly recorded on microfilm using the Eternity RGB laser system.

In contrast to classical color microfilming with its constrained handling flexibility the Eternity provides unbeatable layout and recording flexibility at no extra cost. If one would first produce a microfilm copy by classical photography and subsequently digital image files by scanning, then the metadata is not recorded and preserved on the microfilm.

The metadata does not only ensure a quick reconstruction of the original data structure, but also helps to search specific documents or images in its digital format as well as to retrieve its analog microfilm copy from the repository.

In case the electronically stored data is accidentally lost or damaged, deleted because of manipulations by virus attacks or for cost reasons, or migration problems arise, the preservation film serves as a safe backup medium. Whenever required in the future, the preservation films can be (re)scanned very quickly and its data is available in the digital domain again. Preservation of the microfilm archive is straightforward and inexpensive.

Technology

The Eternity 105 is the first RGB laser COM system for direct recording of digital data on 105 mm color microfilm. Its revolutionary technology is based on RGB lasers, fibre optical beam delivery, and a scanning head in an internal drum configuration (Fig. 3) which ensures highest recording quality and productivity.

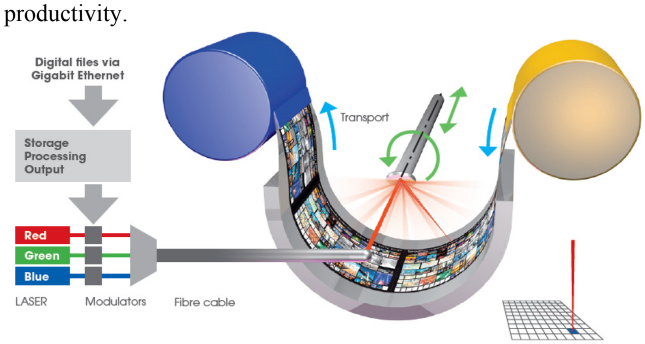

Figure 3*. Eternity's revolutionary recording technology is based on RGB lasers, acousto-optic modulators, fibre optical beam delivery, and an air-bearing scan head in an internal drum configuration.*

The red, green and blue laser beams are modulated according to the incident bit stream of the image data using acousto-optic modulators. Then they are coupled into an optical fibre for flexible beam delivery to the scanning head where the combined beam is focused to a pixel size of about 3 µm. The scanning head is rotating at 6,000 rpm while recording line by line of the image data onto the microfilm which is hold in the drum by vacuum. A piezo-driven linear axis ensures ultra-precise line by line movement of the scanning head.

In the internal drum configuration, the focused RGB laser beams hit the film material in normal incidence all over the exposure area. This ensures high resolution and consistent color quality without the well-known compromising effects of classical camera- and display-based photographic exposure systems. The drum configuration of the Eternity also provides the freedom of recording on different film widths, such as 35 mm, 70 mm, 105 mm or 240 mm.

The high-tech air-bearing scanning system with its submicron resolution providing an ultimate 7,580 dpi is another unique feature of the Eternity device. Thanks to this recording density one single color microfiche offers a storage capacity of up to 3.65 GB of digital image data corresponding to about 100 original A4 color pages scanned with 24-bit and 300 dpi.

Based on its innovative technology and its optimized color calibration algorithm, the Eternity is able to produce true color and greyscale images, finest details and high contrast with a superior productivity. Data can be recorded as analog image and/or digital code. The solid engineering and robust construction of the Eternity is based on proven components from lithography and metrology systems.

The Eternity is connected to the customer's local network via Gbit-Ethernet which ensures high enough data rate to feed the Eternity with a stream of uncompressed Tiff files for recording (Fig. 4). The Eternity provides an unsurpassed productivity of 12 color microfiches/hour (about 1 TB of image data per day).

A 60 m microfilm cassette enables recording of 400 microfiches without reload, hence enabling autonomous recording of 400 color microfiches (about 1.5 TB of image data) within 48 hours of operation.

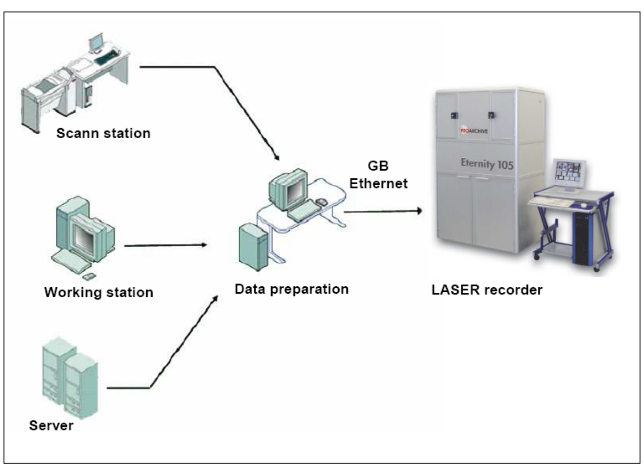

***Figure 4**. The Eternity RGB laser COM system is directly connected to the customer's local network via Gbit-Ethernet.*

Color Calibration

Images to be recorded on microfilm may come in various RGB color spaces, each defined by its relation to the CIELab color space. These color spaces cover slightly different portions of the CIELab space. Therefore, the color calibration algorithm has been optimized for a particular RGb color space - Adobe RGB 98 [10] - instead of compressing the entire CIELab color space onto the microfilm's limited color gamut. As a result, the usable optical density range of the film is exploited to an optimum making it possible to address a high number of quantization steps along the sensitometric curves of the film material.

In general, photographic material exhibits strong non-linearities and limited contrast. For example, the sensitometric curves of the Ilfochrome micrographic film are highly nonlinear and are different for the red, green and blue sensitive emulsions (Fig. 5). In contrast to camera- and display-based photographic exposure devices, RGB laser recording enables to access the full dynamic range of the characteristic curves and hence to address the maximum color gamut of the film.

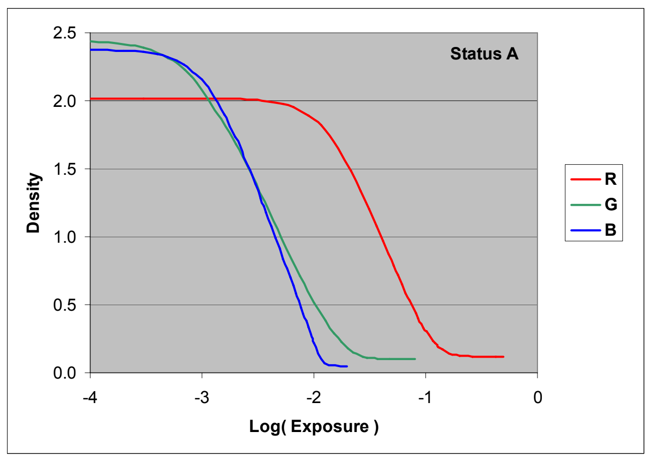

***Figure 5**. Typical sensitometric curves for the Red, Green and Blue sensitive emulsion of the Ilfochrome micrographic film CMM.*

Because the full density range of the microfilm often remains below that of the original image data, appropriate color profiling is needed. Therefore, an innovative color calibration procedure has been developed for the Eternity RGB laser system in order to provide customers image recording capability with optimum color reproduction. A set of specific digital color targets is recorded on color microfilm and is measured using a spectrophotometer. The calibration procedure includes three steps:

- White (black) point calibration;
- Gray scale profiling;
- ICC color profiling.

First, the user can set the minimal (maximal) optical density. The corresponding white (black) point is then calibrated in a few iterations. Second, a neutral gray scale profiling procedure is executed providing a look up table for the Eternity Laser recorder. Finally, a set of color targets is recorded and analyzed to compute an ICC profile using standard color profiling software. Applying the ICC profile to any scanned color images closes the archival chain and restores the colors of the original digital images.

Advantages at a glance

The benefits of data retention concepts beyond digital storage using long-term preservation microfilm are:

- Not vulnerable by computer attacks (virus, worms, Trojans);
- Manipulations are optically detectable;
- Safe preservation of data and metadata;
- Meta data directly attached to object data;
- Microfilms can be (re)scanned very quickly;
- Metadata ensure reconstruction of the original data structure;
- Independent from actual soft- and hardware generations;
- Proven and available since decades;
- Sustainable against water, high temperature and electro-magnetic fields;
- Life expectancy (LE) is up to 500 years;
- Human-readable format;
- No proprietary rights;
- Easily readable by (re)scanning;
- Guaranteed to be upwards compatible.

The benefits of the Eternity RGB laser technology for image data recording on color microfilm are:

- High resolution;
- True colors and gray scales;
- Exceptional image quality;
- High flexibility in adding metadata;
- Unsurpassed productivity (about 1 TB per day);
- High speed recording
- High level of automation;
- Fully embedded in existing workflows;
- Lowest costs per image.

***Figure 6**. The Eternity 105 is the first RGB laser COM system for direct recording of digital image data on 105 mm color microfilm.*

Specifications of the Eternity 105 Laser Recorder

Film cassette	105 mm x 60 m
Film material	Color or b/w microfilm (Ilford, Agfa, Kodak, Fuji)
File format	TIFF 6.0 (Adobe RGB 98) 24 Bit
Resolution	7,580 dpi
Pixel per frame	29,860 x 41,800
Frame size	100 x 140 mm
Storage capacity	3.65 GB
Exposure time	150 s
Productivity	12 microfiches/hour, 1.5 TB per 48 hours, 50,000 microfiches/year

Hybrid Archival Concept – The New Workflow

RGB laser recording enables a straightforward workflow for a hybrid archival concept. Heterogeneous archives (newspapers, image collections, glass plates, manuscripts, etc. in color or b/w) are first digitized at different scan stations. The digital image data can be prepared (e.g. metadata can easily be added) on work stations, and is finally recorded onto color microfilm. And the ever increasing part of "digitally born" data (e.g. digital photography, construction drawings, etc.) hosted on server systems is fed into this new workflow and is directly laser recorded on color microfilm. The implementation of a color calibration profile based on ICC standards on the Eternity laser COM system ensures highest color fidelity for image recording and (re)scanning, such that a print out from the (re)digitized image file is a nearly perfect facsimile of the original.

For digitization of paper materials, some cost calculations were made at NAS [3]. 5 million original A4 documents bound or in sheets, are scanned each year as 1-bit 600 dpi files in automatic feed scanners. The cost for each scanned file (3.3 MB) is $0.15. Scanning of large-format drawings and maps is done in 8-bit grey-scale at 297 dpi in manually fed scanners. The cost for each file (34 MB in average) is $0.92, with 1.3 million image files created per year. In summary, the production costs for digitized image data are $45/GB for the 1-bit files and $27/GB for the 8-bit files, respectively.

The Eternity RGB laser COM system can provide archival copies of these image files on color microfilm for $10/GB, which is 30% of the average digitization costs at NAS.

Based on NARA's cost estimate of $110/GB for digitizing image files [1], color microfilm copies would cost about 9% of the initial scanning costs.

In summary, recording scanned image data on color microfilm offers safe backup and long-term preservation at a very attractive cost level.

The future - Preservation of Audio and Video Data on Color Microfilm

Writing human readable data or image files to microfilm has existed for decades. Converting binary data into images allows microfilm to hold binary data (as illustrated in Fig. 7). The binary data images must be machine readable and the binary microfilm must include unambiguous decoding instructions (e.g. human-readable text) so that in the future computers can read them and retrieve the data back from the binary microfilm. By adhering to these guidelines, digital obsolescence can be overcome and color microfilm becomes a coded optical storage medium for any data formats (such as audio, video, 3d CAD, software-codes, encryption-codes, etc.) with unbeatable longevity and no need from migration for up to 500 years [11, 12].

Although further research and investigations are necessary before this concept can be approved for data preservation, it is obvious that writing large bit-streams onto film will require high-capacity and high-resolution laser COM systems such as the Eternity 105.

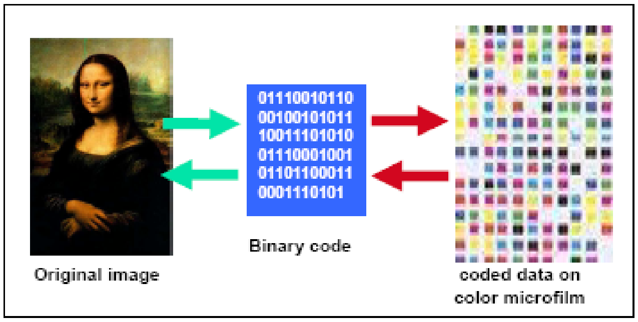

***Figure 7**. Microfilm might be used as a coded optical storage medium with unbeatable longevity and no need from migration for up to 500 years.*

Summary and Conclusion

The Eternity RGB laser COM system offers an excellent solution for accurate and safe long-term preservation of image data on color microfilm. Combining RGB laser recording technology and microfilm sensitometry now enables to archive digital color images in extremely high spatial resolution and with high colorimetric quality.

Furthermore, it has been shown that:

- laser recording of scanned image data on color microfilm costs only 10-30% of the initial digitization costs;
- image preservation on color microfilm is less expensive than storing the uncompressed digital image files on large-scale hard disk server systems;
- laser recording of "bits on film" enables color microfilm to become a coded optical archival medium for all data formats (including audio and video data).

In conclusion, Archives, libraries, museums, publishers and other public and non-public organizations are now provided with an easy to handle high-quality and high-speed recording device which enables them to implement safe and affordable data retention concepts based on color microfilm for archiving beyond digital.

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Author Biography

Daniel Fluck, born 1963, studied physics at the Swiss Federal Institute of Technology (ETH) in Zurich and received a Ph.D. in physics in 1995. He was in a post-doc position at the Institute of Quantum Electronics at ETH until 1999. He has more than 15 years of research and development experience in the fields of nonlinear frequency conversion, optical waveguides and fibres, solid state lasers and laser systems. He is inventor and co-inventor of several patents. In 2005 he founded the start-up company Pro Archive.

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