The CineSave Project: Long-Term Preservation of Digital Productions

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Abstract

The CineSave project was initiated to investigate cinematographic film as a digital storage medium for long-term preservation of film productions. In the digital age, such archiving methods are urgently required, since many films are highly valuable from both economic as well as cultural points of view. The CineSave approach uses "Bits on Film" to store the digital data. In addition, even hybrid approaches have been suggested which allow storing analog and digital information on the same medium. This paper describes the project results of the CineSave project as well as possible further developments which go beyond the scope of the actual project.

Introduction

Film productions are valuable cultural as well as economic assets. At present, European films are publicly funded with about two billion Euros per year [1], and cinema is certainly one of Europe's cultural key components (cf., e.g, [2]). However, the digital data originating from today's film productions is a challenge for archiving, since current migration-based long-term storage approaches are costly, time-consuming, and require permanent financial resources. Therefore, unpredictable burdens are imposed to future generations of our civilization. Consequently, a store-and-ignore approach for long-term storage would be highly desirable. Aside from the lifetime of the storage medium itself, the availability of corresponding reading devices is important. A further crucial issue concerning conventional storage systems is their limited capability to include human-readable information on the same medium. Instructions explaining how to read and decode the digital data are essential to access the content in future.

In order to provide a solution for these problems, the CineSave project was initiated (cf. also [3–5]). Its major aim was to employ "Bits on Film" (i.e., storage of digital data on film) in combination with cinematographic film [6] as a storage medium. The technology "Bits on Film" has gained significant interest during the past few years (cf., e.g., [7–9]). Recent publications deal with error correction [7, 10, 11], channel modeling [12, 13], signal and information processing [14], hardware issues [15], and data storage on color microfilm [16]. The clear advantage of using cinematographic film as a medium for "Bits on Film" is the availability of exposure and reading devices almost all over the world.

This paper is organized as follows: The next sections deal with the project aims, film production and archiving workflows, as well as the project results. At the end of the paper, possible further developments and detailed conclusions are presented.

Project Aims

The CineSave project specifically aimed at preserving audio and video data originating from film productions (see also [3–5]). For an analog production workflow, the original film negative could be used for a relatively reliable long-term preservation in the past. However, film production workflows are mainly digital today. As opposed to using analog long-term preservation on film, it was the intention to employ "Bits on Film" as a digital technology. The project was funded by the German Federal Ministry of Economics and Technology (BMWi) and conducted by Technische Universität Braunschweig and CinePostproduction GmbH from 2009 to 2011.

In CineSave, 35mm cinematographic film should be used for long-term storage of the data. As a major advantage, this medium has been established worldwide for more than a century. A large variety of corresponding exposure and scanning devices is available today, and it was an explicit aim of the project to use such standard hardware components. Besides processing only digital information, hybrid storage, i.e., storage of analog (photographic) and digital information should allow concepts which go far beyond a standard separation master.[1] Also, it should be possible to store digital metadata as well as a human-readable description on how to read and decode the data. Such information should help future engineers to recover the preserved information even after more than a century. The ultimate aim of CineSave is to provide a real store-and-ignore archiving solution.

Film Production and Archiving Workflows

The current workflow for postproduction of feature films is illustrated in Figure 1. Today, most films are still graded in LOG-PD (LOGarithmic Printing Density) color space which is a representation of analog negative densities. Therefore, the original camera negative can be scanned directly to LOG-PD. If digital cameras are employed, all images are still converted to LOG-PD or – if the image data is available in a closely related color space, such as Log-C [18] or S-LOG [19] – commonly just treated as LOG-PD.

Color negatives or separation masters are recorded directly from the negative densities. In order to create DCPs (Digital Cinema Packages) [20], film recording, printing, and analog projection is simulated by means of the so-called *Print Preview LUT* (LUT=LookUp Table). As a result, only colors inside the gamut of the analog film can be reproduced even when dealing with DCPs intended for digital projection.

However, as soon as film distribution is fully digital (and thus not involving analog film) in the future, this limitation is not required anymore. Especially animated feature films can potentially benefit from more saturated primary colors. As an example, the film "Animals United" has been released in 2010 as a DCP with an enhanced color space as well as a separate 35mm version which is limited to

[1] Separation masters are used for analog long-term storage of color images by means of three color separations on black-and-white film (cf. [17]).

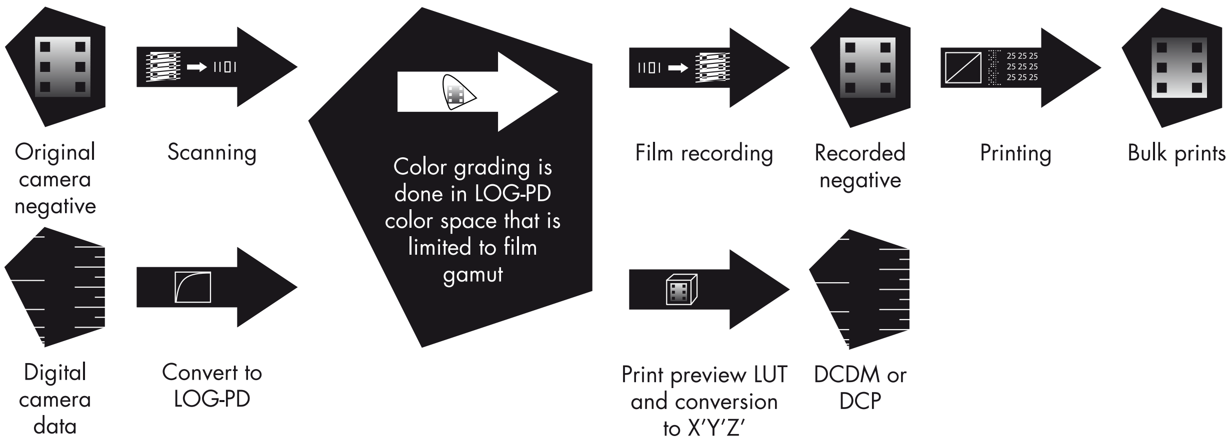

Figure 1. *Current postproduction workflow for feature films.*

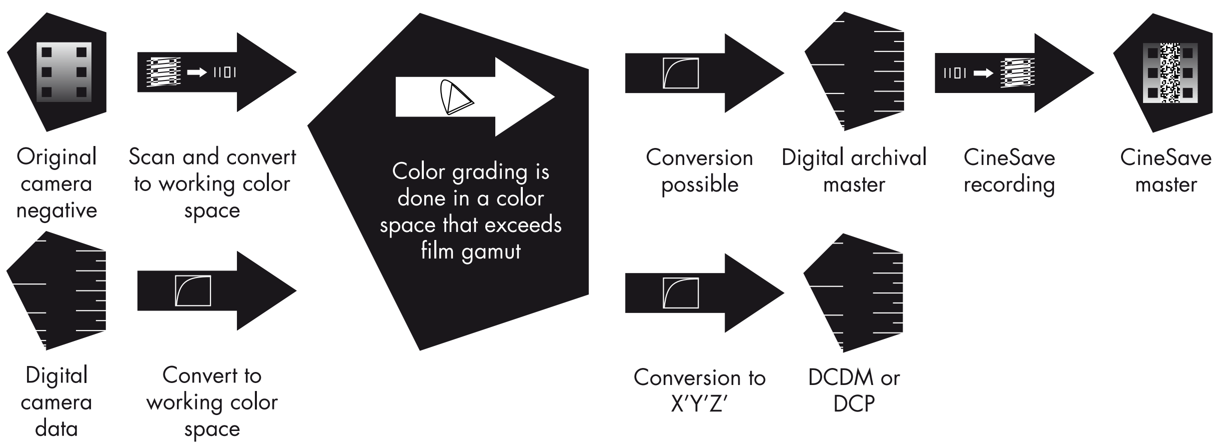

Figure 2. *Proposed future postproduction workflow for feature films.*

analog film gamut. Also, the "Academy of Motion Picture Arts and Sciences" is currently developing an extended postproduction color space as an alternative to LOG-PD [21]. To preserve the original colors, we suggest storing the digital archival master by means of CineSave as illustrated in Figure 2.

Traditional archiving technologies, such as color negatives or separation masters, are not suitable for storing all colors of tomorrow's feature films. When archiving negative densities (either digital, as a color negative, or as a separation master), the final colors strongly depend on the actual type of print film being used for projection in cinemas. Therefore, an accurate color restoration would require reference frames that clearly define the projected colors. Alternatively, an assignment rule which maps the negative densities to the projected colors would have to be stored on each film reel. Increased resolutions, higher frame rates, and additional sound channels pose further challenges to conventional analog archiving. Hence, the viewing experience of tomorrows feature films can only be preserved by archiving the digital master and not by traditional analog film archiving.

Project Results

The major result of the CineSave project has been to realize a complete workflow to store digital data on cinematographic film. Black-and-white film has been chosen as a storage medium because many of these films feature an excellent long-term stability. This kind of film is also successfully used for the already mentioned separation master. As an example, certain black-and-white microfilms exhibit an estimated lifetime of up to 500 years, depending on the specific film material and storage conditions (cf., e.g., [22]). Most tests and experiments have been carried out using Fuji Eterna RDS film [23], since this relatively new material is especially optimized for laser exposure. As an exposure device, the ARRILASER [24] has been employed which is installed in postproduction facilities all over the world. By using a grid space d (i.e., distance between the data points) of $d = 10.71\,\mu$m and assuming 50 frames per meter, a gross storage capacity (i.e., storage capacity which does not consider any overhead due to forward error correction, file system etc.) of 193.8 Mbit/m can be achieved (cf. [3–5]).[2] A microscopic image

[2]By using the full exposure area of the *4K Across Academy* exposure format (cf. also [24]) and assuming 1 Mbit = 1024 kbit and 1 kbit = 1024 bit.

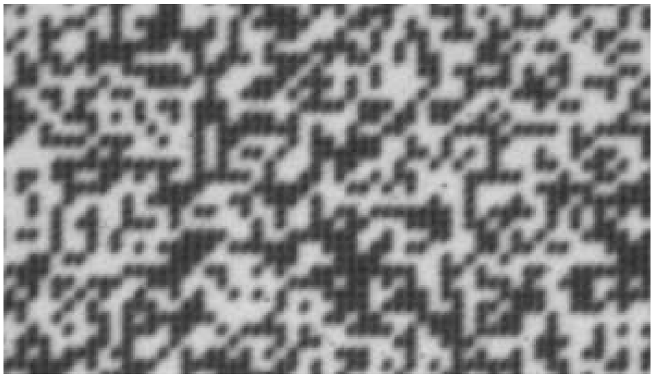

Figure 3. Data points exposed on Fuji Eterna RDS film using the ARRILASER (grid space: $d = 10.71\,\mu\mathrm{m}$).

Figure 4. The film scanning setup constructed in the CineSave project.

of such data points at $d = 10.71\,\mu$m is provided in Figure 3.

Various other black-and-white film materials have also been investigated, such as the Kodak 2238 separation film [25] as well as the sound negative films AGFA ST9 [26] and Kodak 2374 [27]. This is an important fact, since CineSave should not be dependent on the availability of a specific black-and-white film.

For the read-out process, several motion picture film scanners (see, e.g., [28, 29]) have been investigated. However, it turned out from a study of the user requirements that a decentralized read-out process is highly desirable. Since these film scanners are relatively expensive, a low cost film scanner based on standard components has been constructed within the project. This device also proves that reading devices for this type of storage technology can be constructed in the future with acceptable effort and that the read-out can be achieved independently of a specific film scanner model. The film scanning setup (cf. [4, 5]) is shown in Figure 4. It basically consists of standard mechanical and optical components with a total price of only about 5000€ or $6500, respectively. As can be seen in Figure 4, it comprises a digital camera (type "Canon 5D Mark II"), a macro lens, an LED backlight, and a mechanical film transport.

Different possibilities to arrange the data on the film have been suggested as illustrated in Figure 5. Besides the "All Digital Approach" (Figure 5, left), "Hybrid Approaches" allow storing analog image information along with digital data, such as multichannel digital audio, digital color references, as well as virtually any kind of metadata. The combination of an analog 2-perf[3] separation master with digital sound and digital color references is suggested in the middle of Figure 5 (see [4, 5] for a detailed discussion). For a demonstration using the film scanning setup mentioned above, a different approach has been adopted (Figure 5, right). Therefore, three analog color separations are stored along with a digital JPEG2000 color image within a standard 4-perf frame. However, depending on the specific application, virtually any kind of alignment is possible.

The following section describes improvements that may further enhance the results which have been achieved in the CineSave project.

Further Developments

Although the fundamental workflow to realize digital long-term storage on cinematographic film has been demonstrated in the CineSave project, there is a large variety of promising further developments. Since the storage capacity is an important criterion for a digital storage system, methods to improve this parameter are of particular interest. The grid space d significantly influences the storage capacity but its smallest possible value is limited due to intersymbol interference (ISI), i.e., the mutual overlap of adjacent data points (cf. [7, 10]). Also, the standard grid space d_s of the employed ARRILASER film recording device can only be selected according to a small set of predefined values (e.g., $d_s \approx 5.355\,\mu$m for the *4K Across Academy* exposure format) and subsequently d can only be chosen as integer multiples of these values as $d = n \cdot d_s$ $(n = 1, 2, 3, \ldots)$. A further possibility is to employ a diagonal grid to allow the additional intermediate values $d = \sqrt{2} \cdot n \cdot d_s$ $(n = 1, 2, 3, \ldots)$. Based on this method, preliminary examinations have been carried out and the result for $d = 7.57\,\mu$m can be observed[4] in Figure 6. It can be seen that the exposure points are still recognizable but obviously the amount of ISI is increased compared to Figure 3.

Furthermore, tests have been carried out using Fuji Eterna RDS film (which has originally been developed for cinematographic applications) and the Arche laser film recorder [30] at a grid space of $d = 6\,\mu$m. This film recording device works according to the same underlying technical principles as the ARRILASER, but allows higher resolutions and smaller exposed structures, since it has been optimized for microfilm. The result can be seen in Figure 7. Despite the small grid space of $d = 6\,\mu$m, the data points are still distinguishable due to the smaller spot size of the laser beam used for exposure.

When comparing[5] the data points in Figures 3, 6, and 7, it becomes clear that considerable improvements regarding the storage capacity are possible although advanced detection methods may be required. Note that further optimization of the exposure parameters for the variants shown in Figures 6 and 7 may lead to even better results.

[3] When dealing with perforated cinematographic film, *n*-perf means that the employed area spans the height of *n* perforation holes on each side. For analog film projection in cinemas 4-perf is commonly used today.

[4] The image in Figure 6 has been rotated by 45 degrees to allow a better comparability to Figures 3 and 7.

[5] The magnifications are identical for Figures 3, 6, and 7.

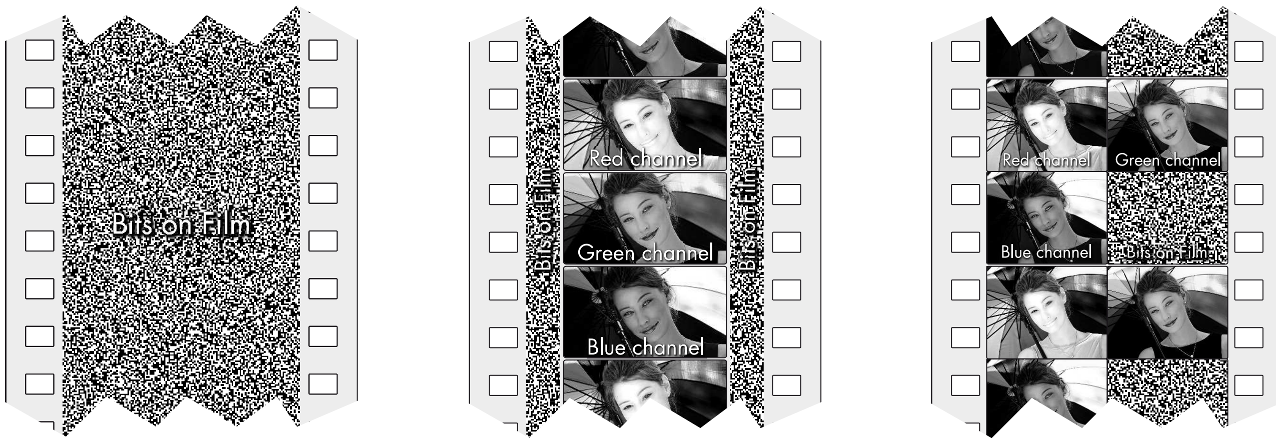

Figure 5. *Schematic illustration of the "All Digital Approach" (left) and different "Hybrid Approaches" (middle/right).*

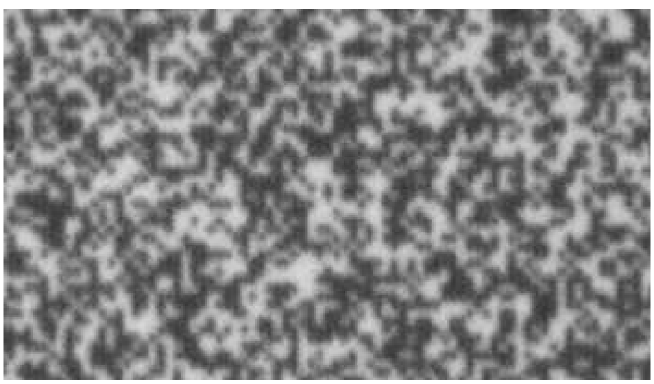

Figure 6. *Data points exposed on Fuji Eterna RDS film using the ARRILASER (grid space: $d = 7.57\,\mu\mathrm{m}$, diagonal grid).*

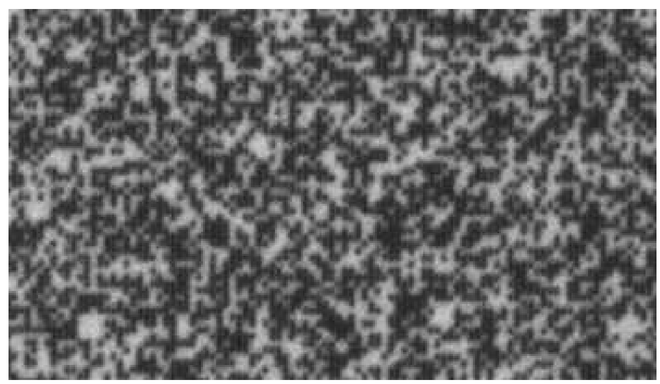

Figure 7. *Data points exposed on Fuji Eterna RDS film using the Arche laser recorder (grid space: $d = 6\,\mu\mathrm{m}$).*

Conclusions

In this contribution, the CineSave project for digital long-term preservation of film productions on 35mm cinematographic film has been described. As an analog medium, this type of film is established all over the world. The storage concepts developed in this project are intended to solve several limitations of digital archiving technologies available today.

As a clear advantage compared to conventional storage systems, CineSave provides a real store-and-ignore archiving solution for digital film productions. Since this archiving approach does not require permanent care and financial resources, the data can even survive times of economical depression and political crisis. Furthermore, the medium is relatively proof against forgery and manipulation due to the required chemical development process. It has been shown in the project that reading devices can be constructed by future generations with acceptable effort. Even human-readable information can be added on the same medium, e.g., explaining how to built a suitable reading device and how to decode the digital data. The project results leave no doubt that CineSave has the potential to play a key role to preserve cultural heritage for future generations.

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References

[1] S. Newman-Baudais, "Public Funding for Film and Audiovisual Works in Europe: A new report from the European Audiovisual Observatory," European Audiovisual Observatory, Strasbourg, France, 2011.

[2] N. Mazzanti, "Digital Agenda for the European Film Heritage – Challenges of the Digital Era for Film Heritage Institutions," Chapter 1.1, European Union, KK-31-12-460-EN-N, 2011.

[3] C. Voges and J. Fröhlich, "Long-Term Storage of Digital Data on Cinematographic Film," in *Proc. of IS&T Archiving Conference*, Salt Lake City, UT, U.S.A., May 2011, pp. 158–161.
[4] C. Voges and J. Fröhlich, "Applications of Data Storage on Cinematographic Film for Long-Term Preservation of Digital Productions," in *Proc. of IBC Conference*, Amsterdam, The Netherlands, Sept. 2011.
[5] C. Voges and J. Fröhlich, "Applications of Data Storage on Cinematographic Film for Long-Term Preservation of Digital Productions," *SMPTE Motion Imaging Journal* (reprint of contribution to IBC Conference 2011), vol. 121, no. 1, pp. 39–42, Jan./Feb. 2012.
[6] The Society of Motion Picture and Television Engineers SMPTE, "SMPTE Standard for Motion-Picture Film (35-mm) – Perforated BH," SMPTE 93-1998, White Plains, NY, U.S.A., 1998.
[7] C. Voges and T. Fingscheidt, "Technology and Applications of Digital Data Storage on Microfilm," *Journal of Imaging Science and Technology (JIST)*, vol. 53, no. 6, pp. 060 505–1–060 505–8, Nov. 2009.
[8] C. Voges, "An Introduction to Long-Term Archiving of Digital Data on Film Material," in *Proc. of VDT International Convention*, Leipzig, Germany, Nov. 2010, pp. 243–249.
[9] F. Müller, P. Fornaro, L. Rosenthaler, and R. Gschwind, "PEVIAR: Digital Originals," *ACM Journal on Computing and Cultural Heritage*, vol. 3, no. 1, pp. 2:1–2:12, June 2010.
[10] C. Voges, V. Märgner, and T. Fingscheidt, "Digital Data Storage on Microfilm – Error Correction and Storage Capacity Issues," in *Proc. of IS&T Archiving Conference*, Bern, Switzerland, June 2008, pp. 212–215.
[11] F. Pflug, C. Voges, and T. Fingscheidt, "Performance Evaluation of Iterative Channel Codes for Digital Data Storage on Microfilm," in *Proc. of IEEE GLOBECOM*, Miami, FL, U.S.A., Dec. 2010.
[12] C. Voges and T. Fingscheidt, "A Two-Dimensional Channel Model for Digital Data Storage on Microfilm," *IEEE Transactions on Communications*, vol. 59, no. 8, pp. 2046–2050, Aug. 2011.
[13] A. Amir, F. Müller, P. Fornaro, R. Gschwind, J. Rosenthal, and L. Rosenthaler, "Towards a Channel Model for Microfilm," in *Proc. of IS&T Archiving Conference*, Bern, Switzerland, June 2008, pp. 207–211.
[14] C. Voges, V. Märgner, and T. Fingscheidt, "Digital Data Storage on Microfilm – The MILLENIUM Project: Signal and Information Processing," in *Proc. of IS&T Archiving Conference*, Arlington, VA, U.S.A, May 2009, pp. 187–191.
[15] D. M. Giel, A. Hofmann, W. Salzmann, and C. Voges, "Digital Data Storage on Microfilm – The MILLENIUM Project: Hardware Realization," in *Proc. of IS&T Archiving Conference*, Arlington, VA, U.S.A, May 2009, pp. 80–81.
[16] C. Voges, V. Märgner, and T. Fingscheidt, "Investigations on Color Microfilm as a Medium for Long-Term Storage of Digital Data," in *Proc. of IS&T Archiving Conference*, Den Haag, The Netherlands, June 2010, pp. 142–147.
[17] P. Z. Adelstein, C. L. Graham, and L. E. West, "Preservation of Motion-Picture Color Films Having Permanent Value," *SMPTE Motion Imaging Journal*, vol. 79, no. 11, pp. 1011–1018, Nov. 1970.
[18] H. Brendel, "ALEXA Log C Curve – Usage in VFX," ARRI Arnold & Richter Cine Technik, Munich, Germany, Oct. 2011.
[19] H. Gaggioni, P. Dhanendra, J. Yamashita, N. Kawada, K. Endo, and C. Clark, "S-Log: A new LUT for digital production mastering and interchange applications," Sony, Tokyo, Japan, 2009.
[20] Digital Cinema Initiative, "Digital Cinema System Specification, Version 1.2," Mar. 2008.
[21] J. Houston, "Overview and Architecture of the Image Interchange Framework," *Presented at Hollywood Post Alliance Tech Retreat*, Rancho Mirage, CA, U.S.A. , Feb. 2008.
[22] Eastman Kodak Company, "KODAK Duplicating (x462), Direct Duplicating (x468), Direct Duplicating Intermediate Microfilm (2470) and Positive Print Duplicating Microfilm (x440) (ESTAR Base), Duplicating Microfilm Datasheet," Rochester, NY, U.S.A., 1999.
[23] FUJIFILM Corporation, "FUJIFILM RECORDING FILM for Digital Separation ETERNA RDS," Datasheet, 2010.
[24] ARRI Arnold & Richter Cine Technik, "ARRILASER Instruction Manual," Munich, Germany, May 2001.
[25] Eastman Kodak Company, "KODAK Panchromatic Separation Film 2238, Technical Information Data Sheet," Rochester, NY, U.S.A., 1998.
[26] Agfa-Gevaert N.V., "Technical Data, ST9, AGFA Panchromatic Sound Recording Film," Mortsel, Belgium, 2001.
[27] Eastman Kodak Company, "KODAK Panchromatic Sound Recording Film 2374 (ESTAR), Technical Information Data Sheet," Rochester, NY, U.S.A., 2001.
[28] ARRI Arnold & Richter Cine Technik, "ARRISCAN – Pushing Film into the Digital World," Product Brochure, Munich, Germany, 2008.
[29] DFT Digital Film Technology, "SCANITY – High Performance, Cost-Effective, Multi-Application Film Scanner," Product Brochure, Weiterstadt, Germany, 2008.
[30] A. Hofmann, W. J. Riedel, K. Sassenscheid, and C. J. Angersbach, "Archivelaser Project: Accurate Long-Term Storage of Analog Originals and Digital Data with Laser Technology on Color Preservation Microfilm," in *Proc. of IS&T Archiving Conference*, Washington, DC, U.S.A., Apr. 2005, pp. 197–200.

Author Biography

Christoph Voges studied electrical engineering at Technische Universität Braunschweig, Germany, and University of Southampton, U.K. He received a Dipl.-Ing. degree in 2005 and joined the Institute for Communications Technology in Braunschweig, Germany, as a research associate after graduating. Currently, he is working as a consultant in the field of digital archiving, especially "Bits on Film." Voges has significantly contributed to several research projects and is author of various scientific publications. His specific research interest is digital data storage on film, including signal and image processing as well as error correction coding. Voges is a member of IS&T, SMPTE, OSA, and IEEE as well as the German societies FKTG, AWV, VDE, and ITG. He is also a delegate at the ITG Technical Committee 3.4 "Film Technology," the AWV Working Committee 6.3 "Data and Storage Management," and the AWV Project Group 6.3.2 "Digital Archiving on Film."

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