APPLICATIONS OF DATA STORAGE ON CINEMATOGRAPHIC FILM FOR LONG-TERM PRESERVATION OF DIGITAL PRODUCTIONS

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ABSTRACT

Long-term preservation of digital film productions is a challenging task. Conventional storage media with relatively limited lifetimes require data migration in certain time intervals. As a result, today's digital archives need permanent care, maintenance, and thus financial resources. On the other hand, many cinematographic film materials offer an excellent long-term stability, and traditional archiving of the (analog) film negatives is a both safe and cost-effective long-term storage solution. This paper is about an innovative approach which aims at using these well-established film materials for storage of digital data by means of „Bits on Film". Various arrangements of the digital data on the film are suggested, optionally also with analog image information on the same medium. A major focus of the paper is on possible applications including a discussion of their practical relevance.

INTRODUCTION

The large amount of digital data originating from today's film productions is a challenge for digital long-term archiving. In the past decades, film negatives could be used for a reliable preservation of feature films, but digital storage media with a relatively limited lifetime (cf., e.g., [1]) require migration (i.e., re-copying) of the data in certain time intervals. A major disadvantage of this approach is the permanent need for financial resources for such digital archives. On the other hand, many film materials exhibit an excellent long-term stability (cf., e.g., [2]) and are therefore excellently suited for long-term archiving applications. A few years ago, a new interest awakened to use these film materials for storage of digital data (cf., e.g., [3,4]), also referred to as "Bits on Film". The fundamental idea to store digital data on film is not entirely new (e.g., [5]). Today, it is a common industry standard, to digitally store multichannel sound on film within the Dolby® Digital or the Sony SDDS® systems on cinema film (cf. [6]). However, the current "Bits on Film" approaches aim at much higher storage capacities and there have already been various contributions to this field of research (e.g., [7-15]). Detailed introductions to this technology are provided in [7,16,17]. Due to its high optical resolution, most of these former approaches are based on microfilm as a storage medium. On the other hand, cinematographic film is a worldwide accepted standard and corresponding recording and scanning devices are available and installed all over the world. Recently, it was suggested to use this kind of material as a basis for "Bits on Film", especially for digital productions [18]. In this context, a research project is currently being conducted by Technische Universität Braunschweig, Germany, and CinePostproduction GmbH, Germany.

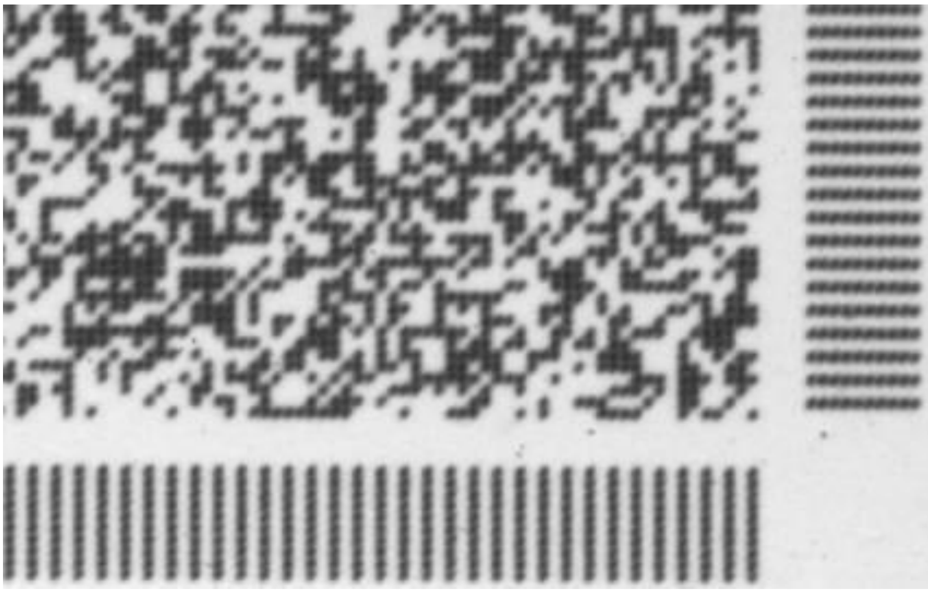

Figure 1 – Microscopic image of a test pattern (binary modulation, *d*=10.71µm) exposed on Fuji Eterna RDS film [20].

This paper is about cinematographic film as a medium for “Bits on Film” with its specific focus on applications in the field of digital productions. The next section summarizes the aims of the research project and provides an overview of the relevant system parameters. It is followed by a section that describes the applications and the practical relevance of the project in more detail. The paper ends with a detailed set of conclusions.

PROJECT AIMS AND SYSTEM PARAMETERS

The aim of the project is a cost-effective store-and-ignore approach for long-term digital archiving based on cinematographic film. Although basically any kind of data can be stored by using this technology, the main focus is on audio and video data originating from digital film productions. A clear advantage is that both recording and scanning devices for this type of film are available and installed almost all over the world – originally for digital postproduction purposes. Furthermore, it shall be possible to construct reading devices in the future with considerable effort. Therefore, as a proof of concept, such a reading device is also being constructed within the project based on standard optical components as well as a digital still camera. Depending on the specific film material and the storage conditions, 100 years or more shall be achieved without migration.

For this project, primarily black-and-white film materials (e.g., [19,20]) have been employed which offer an excellent long-term stability. The ARRILASER [21] has been utilized as a recording device within the project. Figure 1 shows a data pattern exposed at a grid space of *d*=10.71 µm (i.e., the distance between two adjacent data points). To achieve this grid space, the 4K Across Academy exposure format has been used. Since the original grid space of *d*=5.35 µm of this exposure format would lead to a strong overlap of the data points, only every second pixel was exposed in each direction. As suggested in [7,14], binary modulation has been employed. Besides the actual data points, a synchronization pattern can be observed in Figure 1 that serves to identify the exact position of each data point (cf. [9]). File system information has to be added to the digital data to be stored as described in [18]. As a unique property of the medium film, digital as well as analog data (i.e., photographic images) can be stored on the same medium. Accordingly, it is possible to archive also a human-readable description (e.g., decoding instructions or file format specifications) on the film. Of course, in a practical environment, the film may encounter small damages or dust even if it is handled with care, and forward error correction (FEC) is required to ensure virtually error-free reconstruction of the original data (cf. [7,14,15]). Therefore, an FEC encoder adds redundancy to the digital data within the writing process that is used by the FEC decoder to correct errors during the read-out process. By neglecting any overhead, e.g., due to synchronization, file system, and error correction, the so-called gross storage capacity can be calculated. For the above-mentioned exposure parameters this is approximately 193.8 Mbit/m.[1]

APPLICATIONS AND PRACTICAL RELEVANCE

The main mid-term[2] archival medium for a feature film throughout the last century was the edited original negative (or duplicate negatives derived from this negative). With the advent of the digital intermediate, today's feature films are archived in both ways, analog and digital. The analog archival master is typically exposed by means of a laser recorder on color intermediate film. On the other hand, two different digital formats are commonly employed to store the digital representation: Firstly, the Digital Source Master (DSM) on Linear Tape Open (LTO) tapes and secondly a Digital Cinema Package (DCP) [22] which is typically stored in a content management system. As soon as all cinematographic releases will be digital in the future, the color intermediate film will probably become obsolete and only digital data will have to be archived. The only real long-term storage solution currently available is the traditional three-strip separation master on black-and-white film material. However, as an example, a feature film of 110 minutes length typically results in six reels for each separation and six additional reels for the sound negative. Altogether, this results in 24 reels for a 110 minute feature film.

In the project being described in this paper, two entirely new approaches to long-term storage of feature films are proposed by using "Bits on Film": The "Hybrid Approach" and the "Data Only Approach" (see Figure 2).

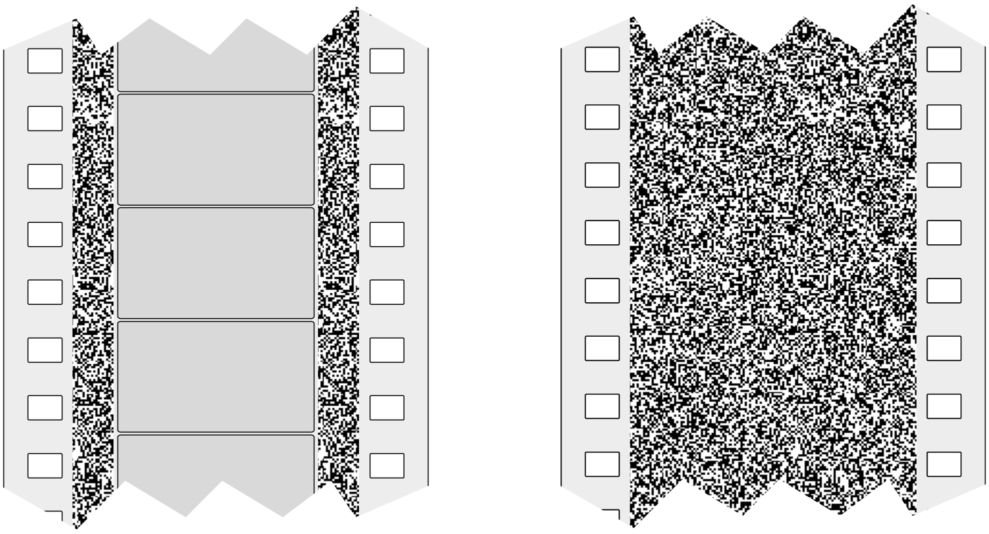

Figure 2 – Schematic illustrations of the "Hybrid Approach" (left) and the "Data Only Approach" (right).

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[1] By using the entire recording area in 4-perf. at d=10.71 µm and assuming 1 Mbit=1024 kbit, 1 kbit=1024 bit, as well as 50 frames per meter.

[2] In this paper, "mid-term" refers to archiving periods from 30–100 years and "long-term" to 100–500 years.

The “Hybrid Approach” is a further development of the traditional separation master process. The center part of the film is used to store the three separations in an interleaved order. Storing the image information in 2-perf. seems to be an ideal compromise between costs and quality as the resolution of modern black-and-white film stock is higher even if compared to original camera negatives with highest resolutions (cf., e.g., modulation transfer curves in [20,23]). Other current approaches to further developed separation master technology also involve reduction of resolution (cf., e.g., [24]). However, our suggested approach has the clear advantage that sound and images are contained on the same negative in the otherwise unused area between the actual picture and the perforation of the film. Thus, the need to create and store a separate set of sound negatives is eliminated. The achieved data rate is sufficient to also include metadata as well as reference frames. Such reference frames (digitally stored and encoded in the X’Y’Z’ color space) can be useful to restore the original color once the film is scanned in future. Furthermore, metadata being kept directly on the negative can further help a future restoration if separate metadata databases are lost over the centuries. Compared to archiving color intermediate and sound negatives recorded in 4-perf., the suggested “Hybrid Approach” using three separations in 2-perf. requires only about 75 percent of the film length. Compared to a standard separation master in 4-perf. and the corresponding sound negative, it requires only about 37.5 percent of the film length.

The “Data Only Approach” uses the full Super 35 mm frame for data storage. For a feature film in 2K resolution the DSM results in around 2 TByte of digital data versus 100 GByte to 300 GByte for the DCP. The color space of the DSM may differ among different production facilities and is subject to change due to technical changes in the workflow of postproduction service providers. This is due to the currently used “Cineon” printing density color space. The ACES/IIF format [25] could solve this issue in future. In contrast to the DSM, the DCP is based on a clearly defined color space (X’Y’Z’), and due to visually lossless and also well-documented (cf., e.g., [22]) compression the file sizes are only around 5 to 15 percent of the corresponding DSM. Additionally, hard- and software for playback of the widely-used DCPs will probably be available for decades. As a result, regarding the current technical situation and economical constraints, the DCP seems to be a very good long-term archival master format. Also, its data rate is very attractive for our suggested approach.

When designing an archival system to store digital data for centuries, it is important to ensure that future engineers are able to recover the information without being dependent on today’s hard- and software systems. To prove the feasibility of realizing a read-out of the data even if film scanners and telecines are no longer available, a scanning device based on standard optical components has been constructed. Major components are a digital still photo camera (Canon EOS 5D Mark II), a stepper motor including controller board, an LED (Light Emitting Diode) unit for constant and uniform illumination, as well as standard computer hardware. The total costs for the devices add up to only about 5000 Euros.

After the film has been scanned, the content of the film reel has to be interpreted. In order to achieve this even after a very long time period, the decoding instructions can be printed as human-readable text on the archived reels. For the *analog* images, these instructions explain how to transfer photographic densities to luminance and chrominance values. The decoding instructions for the *digital* part may, e.g., contain the decoder in a descriptive form or even pseudo code to speed up the implementation of decoding systems. Additionally, the standards for all file formats used should also be printed on the decoding instructions part of the film reel.

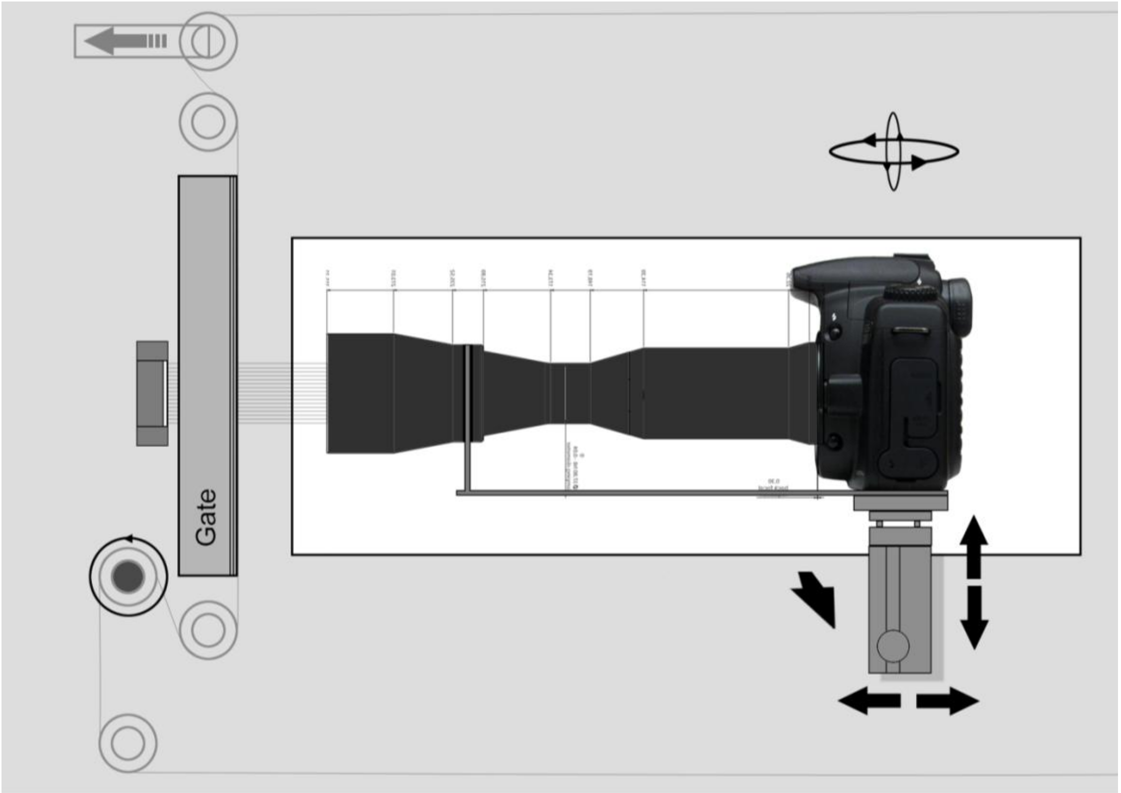

Figure 3 – Schematic illustration of the scanning setup.

Figure 4 – Camera, macro lens, and film gate of the scanning setup.

CONCLUSIONS

In this paper, “Bits on Film” approaches using cinematographic film for long-term storage of digital productions have been discussed. Both recording and scanning devices for this type of film material are available and installed all over the world. Furthermore, the construction of a film scanning device based on standard optical components has been described. Two approaches have been suggested to store a digital production on the film: the “Hybrid Approach” and the “Data Only Approach”, both offering attractive solutions for digital storage of feature films for archiving periods of 100 to 500 years.

The resulting film length of the “Hybrid Approach” is only about 0.75 times the length of the current mid-term archival master (the recorded color intermediate and the sound negative) but the black-and-white film has a better long-term stability compared to the color intermediate film. Compared to a traditional separation master, the “Hybrid Approach” requires about 0.375 times the film length and storage space. Moreover, the quality of the uncompressed sound is better compared to the heavy compression being used for the traditional digital sound negative. Digital reference frames help to restore the original color of the film.

The “All Digital Approach” using DCPs leads to an amount of 35 mm black-and-white film reels comparable to traditional separation masters. However, the “All Digital Approach” does not involve any analog losses. Storing DCPs, as they are distributed to cinemas today will enable future generations for centuries to watch current films in exactly the same image and sound quality as we are watching them today.

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