JPEG2000 for Digital Cinema

Ali Bilgin and Michael W. Marcellin

DTS

5171 Clareton Drive

Agoura Hills, California 91301,USA

Abstract—**JPEG2000 is the latest international standard for image compression. The rich feature set and the state of the art image compression performance make JPEG2000 an attractive alternative for many applications. One of the latest applications to utilize JPEG2000 is digital cinema. Digital Cinema Initiatives (DCI) is a joint venture of seven major Hollywood studios. DCI was formed to establish specifications for an open architecture for digital cinema. As part of these specifications, DCI has selected JPEG2000 for future distribution of motion pictures. In this paper, we provide a brief overview of the DCI specification and discuss how JPEG2000 is utilized within this specification.**

I. INTRODUCTION

Over the last few decades, digital technology has penetrated every facet of our world. Rapid developments in digital technology and information science have transformed many fields. From cell phones to DVDs to the Internet, many of these digital technologies have become embedded in everyday life. While digital technology has already taken over much of the home entertainment market, its penetration into theatrical motion pictures has been slow. Until recently, digital movies could not achieve the level of quality similar to that of 35mm film. However, recent developments in areas such as high-resolution film scanners, digital projection, and image compression have enabled high quality digital cinema exhibition.

These technological advances were recognized by the movie industry. It was also recognized that in order to translate these technological advances into broad-based commercially viable digital cinema exhibition, industry-wide standards would need to be created. To establish such a standard, Digital Cinema Initiatives (DCI) was created in March 2002 [1]. DCI is a joint venture of seven major Hollywood studios (Disney, Fox, Paramount, MGM, Sony Pictures Entertainment, Universal and Warner Bros. Studios). The goal of DCI was to establish a specification for an open architecture for digital cinema. Such a standard would ensure the members of the movie industry that their products and services will be compatible and interoperable with the products and services of other industry members. The final version of the DCI Digital Cinema Specification was published online in July 2005 [1].

JPEG2000 [2,3] is the latest international image compression standard created by a joint committee of ISO/IEC (International Organization for Standardization/ International Electrotechnical Commission) and ITU (International Telecommunication Union). JPEG2000 was developed to address the needs of many applications through its wide set of features. In the summer of 2004, Digital Cinema Initiatives (DCI) selected JPEG2000 as the compression format to be used for digital distribution of motion pictures.

This paper is organized as follows: In the next section, we present a brief overview of the Digital Cinema System as defined by the DCI specification. Section III describes the use of JPEG2000 as the compression method within the DCI specification.

II. DIGITAL CINEMA SYSTEM OVERVIEW

The block diagram of a digital cinema system is illustrated in Figure 1. As depicted in the figure, a digital cinema system can be divided into four stages: Mastering, Transport, Storage and Playback, and Projection. At the mastering stage, the movie is compressed, encrypted, and packaged for delivery to the theaters. The data is then transported to the exhibition site, where it is decrypted, uncompressed, and played back. The DCI specification discusses each of these stages.
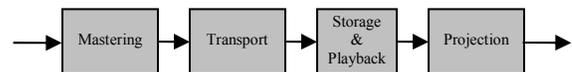

Figure 1: A Digital Cinema System.

A. Mastering

The output of the digital cinema post-production process is referred to as the Digital Cinema Distribution Master (DCDM). The DCDM is a collection of data formats, and includes the structures for image, audio, subtitles, and auxiliary data. The auxiliary data can include information about lighting, curtains, special effects, etc. The steps taken during mastering are depicted in Figure 2. First, the image data in the DCDM is compressed using JPEG2000. Note that the audio is not compressed. The security manager handles encryption and key management. The encrypted files are
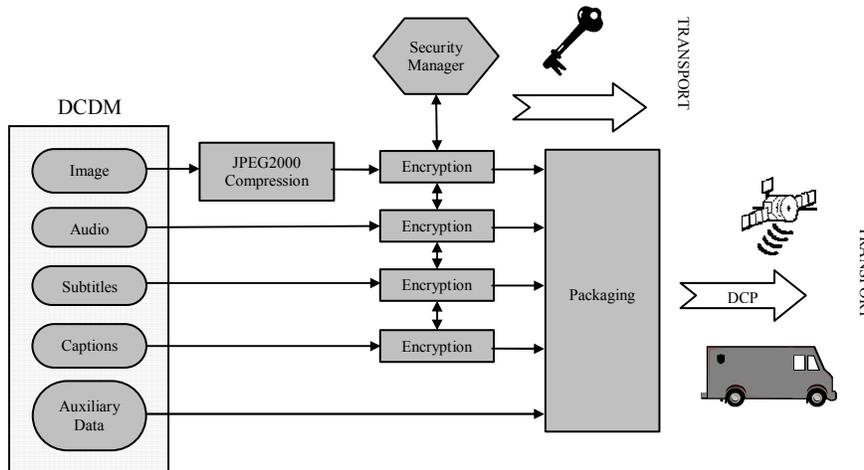
Figure 2: Digital Cinema Mastering.

then packaged to create the Digital Cinema Package (DCP). The DCP is what gets transported to the exhibitors. Packaging uses Material eXchange Format (MXF) specifications [4] and eXtensible Mark up Language (XML) [5].

There are two image structures defined in DCDM: one 2K resolution (up to 2160x1080 pixels) and one 4K resolution (up to 4096x2160 pixels). A device-independent X' Y' Z' color space is used. The bit depth of each color component is 12 bits. The frame rate is set to be 24Hz. In addition, a frame rate of 48Hz is also allowed for 2K content.

It is worth discussing the reason behind allowing two different image resolutions. It is anticipated that there will be both 2K and 4K projectors installed in theaters. The studios can choose to deliver a movie in either 2K or 4K format. The DCI specification requires that all installations should be able to operate using both 2K and 4K DCPs. In the case of a 2K DCP, the sites with 2K projectors can display the image without difficulty. However, it is the responsibility of the 4K playback system to up sample the 2K image for 4K display. Similarly, when a 4K DCP is delivered to a site with a 2K projector, the playback system must downsample. The multi-resolution scalability properties of JPEG2000 may be utilized for this purpose, as discussed in Section III.

B. Transport

The DCI specification does not specify a particular mode of transport. It is envisioned that the transport can be via physical media or over a network. It is required that the content owners' encryption is not removed during transport. It is also required that all of the data of the original files are held intact upon completion of the transport. Thus, no loss is allowed during transmission.

C. Storage and Playback

At the exhibition site, the DCP is unpackaged, unencrypted, and uncompressed to create DCDM* inside a secure media block. This is illustrated in Figure 3. It should

be noted that the difference between DCDM and DCDM* is in the image data and is due to JPEG2000 compression.

It can be seen in Figure 3 that the DCI specification requires the insertion of forensic watermarks into both audio and images. It is required that the forensic watermarking data payload is at least 35 bits. Out of these 35 bits, 16 bits are allotted for a time stamp that can identify the time of the year within 15 minutes. The remaining 19 bits are used to identify the location. All 35-bits are required to be included in each five minute segment. The insertion of the forensic watermarks is required to be performed in real-time. The specification allows the use of up to 30 minutes of content for recovery of the forensic watermarks.

D. Projection

Within the DCI specification, the function of the projector is to convert the digital image data into light that appears on the screen. The DCI specification defines several aspects of the projection system including colorimetry, performance specifications and requirements, and the physical connections to and from the projector.

III. JPEG2000 FOR DIGITAL CINEMA

The DCI specification defines the size of each movie frame to be as large as 4096x2160 pixels[1]. With three color components, 12 bits/pixel/color component, and 24 frames/second, the total size of a three hour feature film exceeds 9 terabytes. Such large sizes make the distribution of uncompressed digital movies impractical. Thus, the DCI specification includes data compression techniques to decrease the size of the image data for economical storage and delivery.

In the summer of 2004, DCI selected JPEG2000 as the compression format to be used for digital distribution of

---

[1] Note that a frame with 4096x2160 pixels contains roughly 8.4 megapixels which is larger than most consumer still image cameras on the market today.
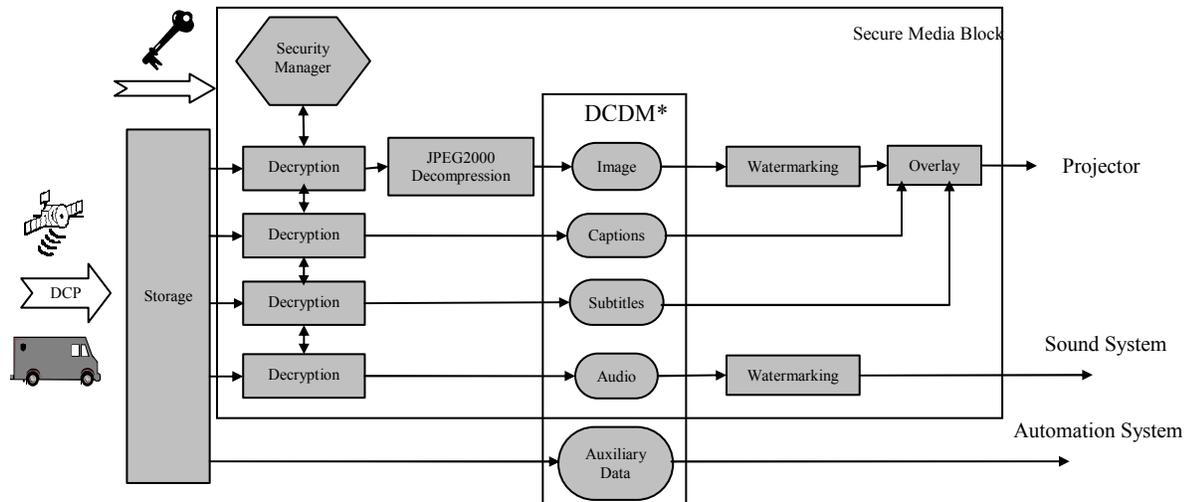
Figure 3: A Simplified Diagram of Digital Cinema Decoding.

motion pictures. The DCI specification requires frames to be compressed individually via JPEG2000. DCI wanted a compression algorithm that was an open standard, so that multiple hardware manufactures would be able to build digital cinema systems. The compression algorithm needed to support high bit depth (e.g., 12 bits per color component). It also needed to support the X'Y'Z' color space without chroma subsampling. Significantly, the compression algorithm needed to support both 2K and 4K resolution projectors from the same file. JPEG2000 satisfies these requirements and more.

The JPEG2000 standard is published in multiple parts. Part I describes the minimal compliant decoder and the codestream syntax. Other parts of the standard describe "value-added" technologies, "Motion JPEG2000" file format, compliance, reference software, an extended file format for document imaging, client/server protocols, protective image security, wireless transmission, 3D image data, and database search tools. The DCI specification is based on Part-1 of the JPEG2000 standard. The particular set of parameters that will be used in digital cinema applications are defined in *JPEG2000 profiles*. A JPEG2000 profile is a set of parameters that are designed to best serve the needs of a particular application. Currently, there are three profiles defined as part of the JPEG2000 standard. Two of these profiles described a restricted set of parameters for use in particular applications, where the third profile is unrestricted. Currently, two additional profiles are being developed for use in digital cinema applications by the JPEG2000 committee.

A. JPEG2000 Digital Cinema Profiles

As mentioned previously, two new JPEG2000 profiles are currently under development to support digital cinema applications. The 2K digital cinema profile describes the parameter set for a 2K DCP, where as the 4K digital cinema profile describes the parameters for a 4K DCP. These profiles are being developed under the understanding that,

once deployed, the decoders shall not be required to be upgraded. Furthermore, enhanced distribution parameter choices will not be allowed in future distribution masters, if they break backward compatibility. For precise details of these profiles, the interested reader is referred to [6]. Restrictions are also defined in DCI Digital Cinema Specification [1]. In this section, we provide an overview of these restrictions.

- The DCI specifications require a 4K decoder to decode all data for every frame in a 4K distribution. Similarly, A 2K decoder is required to decode all data in a 2K distribution. A 2K decoder is allowed to discard the highest resolution level of a 4K distribution. No other data can be discarded. In other words, discarding of data to keep up with peak decoding rates is not allowed.

- The DCI specification requires all decoders to decode each color component at 12 bits/sample. Furthermore, chroma subsampling is disallowed.

- The profiles require the use of the 9/7 irreversible wavelet transform. In other words, the 5/3 reversible wavelet transform is disallowed. It is also required that the decoders implement the inverse wavelet transform in at least 16 bit fixed point precision.

- The profiles require the use of the irreversible color transform (ICT). Note that the ICT is the well-known RGB to YCbCr transform. However, in this case, the input color space is X'Y'Z'. Thus, the transformed components do not correspond to Y, C_b, and C_r.

- Tiling is disallowed. In other words, the entire image should be encoded as a single tile. The image and tile origins are at (0,0).

- The maximum number of wavelet transform levels is 5 for 2K content and 6 for 4K content. In addition,

the number of wavelet transform levels is at least one for 4K content so that a 2K image can be extracted from a 4K codestream using the multi-resolution scalability property of JPEG2000.

- Every color component of every frame of a distribution is required to have the same number of wavelet transform levels.

- Codeblock sizes are restricted to be 32x32.

- Precinct sizes at all resolutions are set to be 256x256, except for the lowest frequency subband, where a precinct size of 128x128 is used.

- Coding style Default (COD), Coding style Component (COC), Quantization Default (QCD), and Quantization Component (QCC) marker segments can only appear in the main header.

- Packed packet headers are forbidden, i.e. no PPM or PPT marker segments are allowed.

- Region of interest (RGN) marker segments are disallowed.

- The progression order for a 2K distribution is required to be Component-Position-Resolution-Layer (CPRL). Progression Order Change (POC) marker segments are forbidden in 2K distributions.

- For a 4K distribution, exactly one POC marker segment is required in the main header. No other POC marker segments are allowed. The POC marker segment ensures that all the 2K data precedes the 4K data in the codestream. In addition, within the 2K and 4K segments, all data for color component 0 precede all data for color component 1 which in turn precede all data for color component 2.

- Each compressed codestream of a 2K distribution has 3 tile parts where each tile part contains one color component. Similarly, each compressed codestream of a 4K distribution has 6 tile parts. The first three tile parts contain data that are necessary to decompress a 2K color component. Each of the remaining three tile parts contains the additional data needed to decompress one color component at 4K resolution.

- Tile part Lengths, Main header (TLM) marker segments are required. These marker segments can be used to identify the location of each tile part in the codestream for quick access.

- Only a single quality layer is allowed.

- There are constraints on the maximum sizes of codestream segments as well as the total size of the codestream. Specifically,

    o For a 2K distribution with a frame rate of 24 fps, the total size of a frame can not exceed 1,302,2083 bytes. In addition, the size of each color component can not exceed 1,041,666 bytes.

    o For a 2K distribution with a frame rate of 48 fps, the total size of a frame can not exceed 651,041 bytes. In addition, the size of each color component can not exceed 520,833 bytes.

    o For a 4K distribution, the total size of a frame can not exceed 1,302,2083 bytes. In addition, the 2K portion of each color component can not exceed 1,041,666 bytes.

These size constraints correspond to a maximum total rate of 250 Mbits/second. At these rates, the total size of a 3 hour feature film is roughly 314 gigabytes.

REFERENCES

[1] http://www.dcimovies.com
[2] ISO/IEC 15444-1. JPEG2000 Image Coding System, 2000.
[3] D. S. Taubman and M. W. Marcellin, JPEG2000: Image Compression Fundamentals, Standards and Practice, Kluwer Academic Publishers, Boston, 2002.
[4] SMPTE 377M-2004. Television – Material Exchange Format (MXF) – File Format Specification.
[5] http://www.w3.org/TR/REC-xml/
[6] ISO/IEC 15444-1:2004/FDAM 1 - Information technology - JPEG 2000 image coding system: Core coding system, AMENDMENT 1: Profiles for Digital Cinema Applications.