JPEG2000 Image Coding System Theory and Applications

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Abstract— **JPEG2000, the new standard for still image coding, provides a new framework and an integrated toolbox to better address increasing needs for compression. It offers a wide range of functionalities such as lossless and lossy coding, embedded lossy to lossless coding, progression by resolution and quality, high compression efficiency, error resilience and region-of-interest (ROI) coding. Comparative results have shown that JPEG2000 is indeed superior to established image compression standards. Overall, the JPEG2000 standard offers the richest set of features in a very efficient way and within a unified algorithm. The price of this is its additional complexity, but this should not be perceived as a disadvantage, as the technology evolves rapidly.**

I. INTRODUCTION

The JPEG2000 international standard represents advances in image compression technology where the image coding system is optimized not only for efficiency but also for scalability and interoperability in network and mobile environments. Digital imaging has become an integral part of the Internet and JPEG2000 is a powerful new tool that provides power capabilities for designers and users of networked imaging applications [1].

With the progress of multimedia and Internet applications, the needs and requirements for image coding technologies grew and evolved. In March 1997, a call for contributions was launched for the development of a new standard for the compression of still images. This effort produced the JPEG2000 image coding International Standard in December 2000 (ISO 15444 / ITU-T Recommendation T.800) [2,3]. Part 1 of the standard describes the core coding system, consisting of a limited number of possible coding algorithms, in order to provide maximum interchange. Part 2 consists of optional technologies not required for all implementations. Evidently, images encoded with Part 2 technology will not be able to be decoded with Part 1 decoders. As an example, Part 2 includes variable DC offset, multiple component transformations, Trellis Coded Quantization, user defined wavelets, arbitrary wavelet decompositions, general scaling-based ROI coding, and advanced error resilience schemes (Fig. 1). It is actually a toolbox with technologies useful for various specialized applications. Part 3 defines motion JPEG2000 (MJ2 or MJP2) and is based on Part 1 of JPEG2000. MJ2 will be used in many different areas, as for example in applications where it is desired to have a single codec for both still pictures and motion sequences (which is a common feature of digital still cameras), or in applications where very high quality motion pictures are required (e.g. medical imaging and motion picture production), or in video applications in error prone environments (e.g. wireless and the Internet). JPEG2000 compressed image sequences, synchronized audio and metadata can be stored in the MJ2 file format. Motion JPEG2000 is also targeting interoperability with the JPEG2000 file format (JP2) and the MPEG-4 file format (MP4). A new ad hoc group was created in Oct. 2002 (the Motion JPEG2000 for Medical Imaging) for the promotion of the JPEG2000 standards in the medical community. Part 4 of the standard defines the conformance testing. Part 5 defines the reference software (high quality free software). Two reference software implementations do exist, namely, the JJ2000 software in Java and the JasPer software in C. The Kakadu software is also available [2]. Part 6 defines the compound image file format. Part 7, originally intended to produce a technical report with guidelines of minimum support function of Part 1, has been withdrawn. Part 8 addresses security issues such as authentication, data integrity, protection of copyright and intellectual property, privacy, and conditional access. Part 9 defines interactivity tools, APIs and protocols for the transmission of JPEG2000 images over a client/server environment. Part 10 extents the JPEG2000 algorithm to 3D image compression and floating point data [4]. Part 11 defines a file format for image compression and transmission in wireless environments such as mobile, wireless LAN and Radio. Part 12 defines the common file format for MPEG-4 and Motion JPEG2000. Finally, the purpose of Part 13 is to define a normative entry

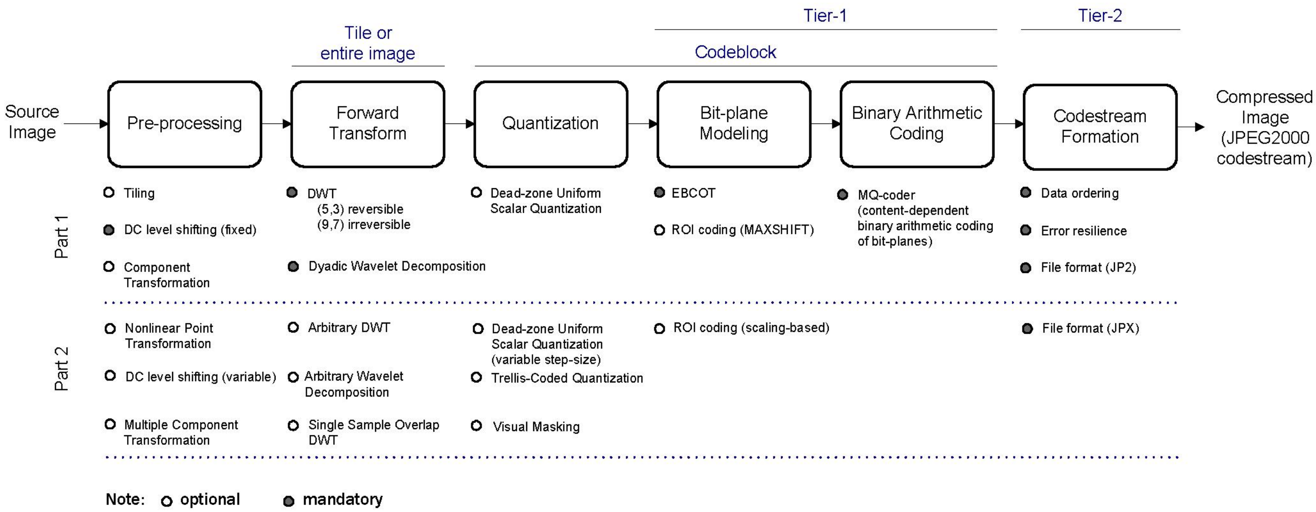

Figure 1: The JPEG2000 image compression architecture

level JPEG 2000 encoder providing one or more optional complete encoding paths that use various features defined in the JPEG2000 standards. This part intends to standardize an entry level encoder that can be used in various applications with guidelines on its use, based on patents for which royalty and license fee free declarations are available.

JPEG2000 is inherently more complex than its predecessor, JPEG. Its reliance on the discrete wavelet transform (DWT) and coding of wavelet coefficients in blocks, together imply a significantly higher cost in memory consumption than the baseline JPEG algorithm [2,3]. The embedded entropy coding algorithm is far from trivial to implement and the code-stream parsing rules involve considerable conceptual complexity. The most demanding parts of the JPEG2000 engine are the DWT and the entropy coding. Actually, EBCOT (Embedded Block Coding with Optimized Truncation) consumes more than 50% of the total clock cycles required to compress an image because of bit-wise processing in every bit-plane of the code-blocks [3]. Numerous architectures, both hardware [5,6] and software [7], have been proposed so far to reduce the computational and memory requirements. The demanding architecture of the JPE2000 is anticipated by its coding efficiency, which is much higher than that of the other coding approaches or standards, both for the lossless and lossy cases. This is particularly true when the additional features offered by the JPE2000 are also taken into account [8,9]. As a rule of thumb, the JPE2000 performs better by approximately 2dB than the JPEG for all compression ratios (lossy case). In the following a brief description of the JPEG2000 encoder is given and some interesting multimedia applications, that already have adopted the JPEG2000 standard, are presented.

II. JPEG2000 Compression Architecture

Figure 1 shows an illustration of how an image is transformed through the different stages of JPEG2000 encoding process. It is worth mentioning that, unlike many coding schemes, the JPEG2000 compression can be both lossy and lossless. This depends on the wavelet transform and the quantization strategy applied. JPEG2000 also allows for image tiling. The term ‘tiling’ refers to the partition of the original (source) image into rectangular non-overlapping blocks (tiles), which are compressed independently, as though they were entirely distinct images. Arbitrary tile sizes are allowed, up to and including the entire image (i.e. no tiling). Tiling reduces memory requirements and constitutes one of the methods for the efficient extraction of a region of the image.

A. Wavelet Transform

Tile components are decomposed into different decomposition levels using a separable wavelet transform. A decomposition level is related to the next decomposition level by spatial powers of two. Part 1 of the standard supports dyadic decomposition only, as this appears to yield the best compression performance for natural images. The DWT can be irreversible or reversible. The irreversible transform in Part 1 of JPEG2000 is implemented by means of a 9-tap/7-tap filter bank. The reversible transformation in Part 1 of JPEG2000 is implemented by means of a 5-tap/3-tap filter bank. The actual wavelet transform implementation can be done in two ways, namely, by conventional convolution and down-/up-sampling, or by lifting. Lifting consists of a sequence of very simple filtering operations for which alternately odd sample values of the signal are updated with a weighted sum of even sample values, and even sample values are updated with a weighted sum of odd sample values. In both implementations, the signal should be first extended periodically. This periodic symmetric extension is used to ensure that for the filtering operations that take place at both boundaries of the signal, one signal sample exists and spatially corresponds to each coefficient of the filter mask.

B. Quantization

At the encoder, the scalar quantization operation maps a given coefficient value to a quantizer index, which is then encoded as part of the compressed bit stream. At the decoder, the quantizer index is decoded and converted into the corresponding quantized value. This operation is lossy, unless the quantization step size is 1 and the coefficients are integers, as produced by the reversible integer 5/3 filters. Each of the transform coefficients $a_b(u,v)$ of the subband b is uniformly quantized to the value $q_b(u,v)$. One quantization step size per subband is allowed. All quantized transform coefficients are signed values even when the original components are unsigned. These coefficients are expressed in a sign-magnitude representation prior to entropy coding.

C. Entropy Coding

Each subband of the wavelet decomposition is divided up into rectangular blocks, called *code-blocks*, which are coded independently using arithmetic coding by means of an approach called EBCOT. Such a partitioning reduces memory requirements in both hardware and software implementations and provides a certain degree of spatial random access to the bit-stream. The block size is identical for all subbands, so that the blocks in lower resolution subbands span a larger region in the original image. A neighborhood of spatially consistent code-blocks from each subband at a given resolution level forms larger rectangles, called *precincts*. Code-blocks are coded a bit-plane at a time, starting with the most significant bit-plane with a non-zero element to the least significant bit-plane. For each bit-plane in a code-block, a special code-block scan pattern is used for each of the three passes, i.e. the significance *propagation* pass, the *magnitude refinement* pass and the *clean-up* pass. Each coefficient bit in the bit-plane is coded in only one of the three passes. A rate distortion optimization method is used to allocate a certain number of bits to each block.

D. Multiple-Component Image Coding

JPEG2000 supports multiple-component images. Part 1 of the standard supports two different component transformations, one irreversible component transformation (ICT) and one reversible component transformation (RCT). The ICT may only be used for lossy coding and is the same transform used to convert RGB to YC_bC_r components. The RCT may be used for lossy or lossless coding. It is a decorrelating transformation, which is applied to the three first components of an image. Three goals are achieved by this transformation, namely, color decorrelation for efficient compression, reasonable color space with respect to the Human Visual System for quantization, and ability of having lossless compression, i.e. exact reconstruction with finite integer precision. For the RGB components, the RCT can be seen as an approximation of a YUV transformation.

III. JPEG2000 Functionalities

The JPEG2000 standard exhibits a large number of functionalities (features), among which one can mention regions of interest coding/decoding, resolution and quality scalability, and error resiliency.

A. Region-of-Interest (ROI)

ROI is a feature allowing for coding or decoding of certain regions in an image with better quality when compared to the rest (background) of the image. This is performed by scaling up coefficients influencing the ROI so that the bits associated with that ROI are placed in higher bit-planes. During the embedded coding process, those bits are placed in the bit-stream before the non-ROI parts of the image. The ROI approach defined in the JPEG2000 Part 1 performs scale up shifts by values such that the bit planes for ROI are completely separate from those for the rest of the image. This is referred to as MAXSHIFT and allows ROI coding of arbitrary shaped regions without the need for shape information.

B. Scalability

The new standard emphasizes scalable image representations. Portions of the compressed code-stream may be extracted and decompressed independently, to recover the image at a reduced resolution, at a reduced quality (SNR) within any given resolution, or within a reduced spatial region, at the desired resolution and quality. JPEG2000 also supports entirely lossless compression of images without sacrificing scalability. This means that an application is able to extract progressively higher quality representations of any given spatial region, leading eventually to a lossless representation of that region. These features provide applications and users with new paradigms for interacting with compressed imagery. The wavelet transform and bit plane coding in JPEG2000 algorithm allow for resolution and quality scalability types by an adequate construction of the bit-stream.

C. Error Resilience

Many applications require the delivery of image data over error prone communication channels. Typical wireless communication channels give rise to random and burst bit errors. Internet communications are prone to packet losses due to traffic congestion. To improve the performance of transmitting compressed images over these error prone channels, error resilient bitstream syntax and tools are included in the JPEG2000 standard. The error resilience tools include segmentation symbols to confine error propagation and localization, predictable termination in arithmetic coding to detect errors, and various synchronization markers.

IV. Applications

JPEG2000 has been designed in order to be used in a variety of multimedia applications. Since the approval of JPEG2000 core coding system Part 1, more than 300 implementations in both hardware and software have been released in form of products and solutions. In addition, JPEG2000 has been adopted as a component in a number of industry and international consortia. One of the recent achievements of JPEG2000 standard has been its adoption for Digital Cinema Applications [10]. In the remainder of this section, we cover examples of a few other applications where JPEG2000 coding standard has been successfully deployed.

A. JPEG2000 for Archival of Visual Content

Archival of digital information has been an exciting topic of research and development in the past years [11,12]. This is especially important for digital preservation and storage of content in libraries. Several initiatives have been considering the use of JPEG2000 as a solution for storage of visual content in different environments. Among others one can mention recent efforts by Google for on-line access of digital publications, and the projects by the Library of Congress for storage of their content. The reason behind such a choice has been often justified by the fact that JPEG2000 allows lossless coding; it provides high quality results when compared to alternative solutions; it provides the possibility of storage and retrieval of visual content in multiple versions in terms of quality and resolutions. The royalty free and license-fee free nature of JPEG2000 has also been an important element in the adoption of JPEG2000 compression for such applications.

B. JPEG2000 in Geospatial Imaging

Geospatial imaging applications often produce an enormous amount of content with very high resolutions and require very high quality. Recently, the National Imagery and Mapping Agency (NIMA) in USA, and NATO have adopted JPEG2000 compression as their preferred compression format for all new imagery systems. Hence, the Basic Image Interchange Format (BIIF) used in interchange of maps and other imagery data currently includes a profile which allows applications to recognize JPEG2000 compressed data. Several commercial solutions are available from manufacturers for such applications.

C. JPEG2000 in Medical Imaging

Since its earliest days in JPEG2000 standardization, medical imaging has been one of the identified applications. Therefore special efforts were made in order to cope with requirements of such applications. WG4 of Digital Imaging and Communications in Medicine (DICOM) played an important role in definition of requirements retained within JPEG2000 in medical imaging applications, and currently JPEG2000 is among the formats supported by DICOM.

D. JPEG2000 in Video Surveillance

JPEG and MPEG-4 compression standards have been widely used in video surveillance applications. Thanks to features offered by JPEG2000 standard, recent video surveillance systems have started to consider the use of this compression algorithm. The main reasons for such an adoption have been complexity issues, possibility of region of interest coding, high compression efficiency, and possibility of securing compressed images by means of JPSEC extension.

V. Conclusions

JPEG2000, the new standard for still image coding, provides a new framework and an integrated toolbox to better address increasing needs for compression. It offers a wide range of functionalities such as lossless and lossy coding, embedded lossy to lossless coding, progression by resolution and quality, high compression efficiency, error resilience and region-of-interest coding. Comparative results have shown that JPEG2000 is indeed superior to established image compression standards. Overall, the JPEG2000 standard offers the richest set of features in a very efficient way and within a unified algorithm. The price of its additional complexity should not be perceived as a disadvantage, as the technology evolves rapidly.

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