A Study on State-of-the-Art Image Compression Algorithms and Standards

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Abstract - This paper presents an overview of best in class of image compression algorithms and standards such as JPEG and JPEG-2000 which are commonly and widely employed in the field of image processing domain. These principles are applied equally well to multimedia data, for instance,, audio, video, natural images and various other types of data. This paper also discusses the essential ways and means of compression by utilizing the distinctive types of methodologies and techniques, for example, variable-length codes, run-length encoding, dictionary-based compression, transforms and quantization. The abstract formulations are given keeping in mind the end goal to enable the research scholar to perceive and distinguish the exploration issue and to discover the possibility, feasibility and practicality for investigating them. This motivates us to investigate the problem of image compression and to analyze the issues further in an effort to understand whether we have accomplished some hypothetical points of confinement.

Keywords – Image compression algorithms, JPEG, JPEG2000, Huffman, Arithmetic, Run length, Dictionary, DCT, DWT, Compression standard

I. INTRODUCTION

It is well known that data compression is one of the successful, predominant and inevitable areas in the field of image processing in general and multimedia communication and multimedia computing based on web technology in particular [1],[3]-[5]. It is a subject of much significance for research scholars, academicians and industries globally and has got many applications in every sphere of the life [2]. Data compression strategies, methods and techniques have been studied for almost four decades [3]-[4]. The compression algorithms and coders have been evaluated in terms of the amount of compression they provide, algorithm efficiency and susceptibility to error [6]. While algorithm efficiency and susceptibility to error are relatively independent of the characteristics of the source ensemble, the amount of compression achieved depends upon the characteristics of the source to a great extent.

Image compression is a key issue in modern and the Internet based communications [6]-[7]. As the computer communications revolution continues to expand, the requirement for data storage and transmission continue to soar and beyond our expectation [2],[4]-[5]. Image compression is the process of reducing the number of bits required to represent an image. With data compression, one can store more information in a given storage space and transmit information faster over communication channels [2],[6].

Uncompressed text, graphics, audio and video data require extensive and considerable storage capacity given today's storage technology. Similarly for multimedia communications, data transfer of uncompressed images and video on the computerized systems over digital networks require very high data transfer capacity and bandwidth. For instance, an uncompressed still image of size 640x480 pixels with 24 bit of colour requires around 7.37 Mbits of storage and an uncompressed full-motion video (30 frames/sec) of 10 sec duration needs 2.21 Gbits of storage and a bandwidth of 221 Mbits/sec. Even if we assume that there is sufficient storage limit accessible, it is difficult to transmit vast number of images or play video (sequence of images) progressively due to insufficient data transfer rates as well as limited network bandwidths. In outline, at the present circumstance with advancement, the main arrangement is to compress multimedia data before its storage and transmission, and decompress it at the recipient for play back [9].

Data compression is done by eliminating redundancies and irrelevancies of the image. In a nut shell, compression is accomplished by removing and expelling duplication and unimportant matters of the image [4].Redundancy reduction and elimination aims at keeping away the duplication from the signal source of image or video content. Irrelevancy reduction omits parts of the signal that will not be noticed by the signal receiver namely Human Visual System (HVS). Image compression research aims at reducing the number of bits needed to represent an image by removing the spatial and spectral redundancies as much as possible. Redundancies in the image can be classified into three categories, namely, inter-pixel repetition or spatial redundancy, psycho-visual excess and coding repetition.

The inter pixel and coding redundancy of an image can be removed and expelled based on the statistical approach [8]-[9].

Therefore, the modern image compression techniques and strategies offer an answer for this issue by reducing the storage requirements and transmission bandwidths. However, the most important compression technique for still images is the transform coding based on the Discrete Cosine Transform (DCT). This is used in the popular JPEG standard. In recent years, wavelet transform has become a cutting-edge technology in signal processing in general and in image compression in particular. In fact, JPEG-2000 standard, the top contenders are Discrete Wavelet Transform (DWT) based compression algorithms [11]-[12].

The rest of this paper is composed as takes after: Section II is given to the literature survey on image types and storage formats which are broadly and commonly used in the field of image handling domain. In Section III and IV, we address the essential strategies and procedures utilized for gray scale image compression and their constraints utilized in the image coding framework. Section V deals with the symbol encoders. Importance of the standardization process and the most prevailing industry standards, for instance, JPEG and JPEG-2000 families are discussed in the section VI. Conclusion and future scope of the proposed research work are presented in the Section VII.

II. DIGITAL IMAGE FILE FORMATS

Image file formats are standardized means of organizing and storing digital images. Image files are composed of digital data in one of these formats that can be rasterized for use on a computer display or printer [27]. An image file format may store data in uncompressed, compressed, or vector formats. Once rasterized, an image becomes a grid of pixels, each of which has a number of bits to designate its color equal to the color depth of the device displaying it [28]-[30].

1. JPEG

The term JPEG stands for "Joint Photographic Experts Group" since that is the name of the council that developed the format for the still images [27]. The JPEG format is generally utilized for compressing photographic images because of true colour and high-resolution image data. It is a lossy configuration, which implies and infers some quality is lost when the picture is compacted. On the off chance that the picture and image is packed and compressed excessively, the output pictures end up being perceptibly "blocky" and a portion of the subtle element is lost.

2. GIF

GIF stands for "Graphics Interchange Format" which is an image file format commonly and regularly utilized for document design using pictures and images on the web [28]. Unlike the JPEG image group, GIFs uses lossless compression that does not debase and degrade the quality of the image and picture. GIF file format supports a a maximum of 256 colors. Since GIFs may simply contain 256 colours, they are not ideal for storing advanced photographs, for example, those caught with a computerized camera. Therefore, the JPEG format, which supports millions of colors, is more commonly used for storing digital photos.

3. PNG

PNG, which can be pronounced "ping" or "P-N-G," is a packed raster realistic image format [27]-[29]. It is commonly and regularly used on the web and is likewise a mainstream decision for application design. PNG joins an impressive and noteworthy benefits of both JPEG and GIF positions. This is a critical qualification amongst GIF and PNG, since GIF pictures can fuse a most amazing of 256 hues.

4. BMP

It can be professed and pronounced as "knock,""B-M-P," or just a "bitmap picture" [30]. The BMP is a routinely used raster sensible arrangement for sparing picture records. It was presented on the Microsoft Windows stage in mid 1990. The BMP design stores shading information for every pixel in the image with no compression. The JPEG and GIF configurations are likewise bitmaps, yet utilize compression algorithms that can altogether diminish their storage size. BMP pictures and images are frequently utilized for printable images.

5. TIFF

TIFF stands for "Tagged Image File Format" which is a graphics file format for handling color depths ranging from 1-bit to 24-bit [27]. Since the main TIFF standard was exhibited, people have been making various little improvements to the plan, so there are right now around 50 assortments of the TIFF designs. Such a great amount for a widespread arrangement. As of late, JPEG has turned into the most famous all inclusive arrangement, in view of its little record size and Internet similarity.

III. TRANSFORM CODING

Transform based image coding is a mathematical framework which is a divide and conquer strategy for exploiting the dependencies of the image data so that the quantization and entropy coding can be applied easily and effectively. Subsequently, image compression can be achieved by reducing or eliminating any redundancies in the input image, which usually leads to bit savings [18]-[20]. Figure 1 demonstrates a transform based image compression model. It consists of a mapper, a quantizer and an encoder.

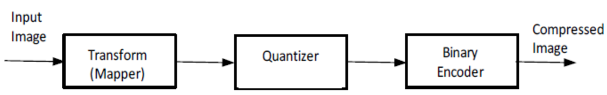

Fig 1 Block Diagram of the Image Compression

1. Mapper

A mapper transforms a two-dimensional (2-D) image from the spatial domain to the frequency domain. In other words, it reduces interpixel redundancies of the input image. This operation is generally reversible. An effective transform will concentrate useful information into a few of the low-frequency transform coefficients. An HVS is more sensitive to energy with low spatial frequency than with high spatial frequency [21]-[23].

2. Quantizer

Compression can be achieved by quantizing the coefficients so that important coefficients (low-frequency coefficients) are transmitted and the remaining coefficients are discarded. A quantizer is used to reduce the psycho visual redundancies of the input image. This operation is not reversible and must be omitted if lossless compression is desired.

3. Entropy encoder

The entropy encoder is used to create a fixed or variable-length code to represent the quantizer's output and maps the output in accordance with the code. In most cases, a variable-length code is used. This operation is reversible [21]-[23].

4. Transform Techniques

There are many types of image transform like discrete Fourier transform (DFT), discrete sine transform (DST), discrete cosine transform (DCT), Karhunen-Loeve transform (KLT), Slant transform, Hadamard transform and discrete wavelet transform (DWT). For compression purposes, the higher the capability of energy compaction, the better the transform. Though KLT transform is best in terms of energy compaction (transform coding gain), one drawback of KLT transform is that it is data dependent and overhead of sending the transform may reduce the transform coding gain. Another popular transform is discrete cosine transform (DCT),

which offers transform coding gain closer to KLT and higher than DFT[16]. In addition, the computational complexity of DCT is less than DFT. Due to these reasons, DCT has become the most widely used transform coding technique in JPEG.

DCT based image coder produces blocking artifacts at the high compression ratio and that is why DWT is preferred for JPEG-2000 bench mark [16]-[17],[27].

IV. IMAGE COMPRESSION AND CODING MODELS

Technically speaking, images and pictures are two-dimensional signals received by the human visual system (HVS). At the point when an image is digitized, it becomes a digital image. The most basic requirement for digital image compression is the digitization of an image object (or simply an image) such as a physical picture, a document page and so forth. The digitization of an image involves two processes, sampling and quantization. The sampling process maps a physical image into an array of pixels by spatially sampling points of the physical image. The quantization process, on the other hand, uses a limited number of bits to represent each pixel.

Quantization is the process of converting a continuous range of values into a finite range of discreet values. In other words, quantization is the process of mapping a large set of input values to a (countable) smaller set. Digital image quantization is the process of determining which parts of an image coefficients can be discarded or disposed in order to consolidate with minimal subjective loss. Image quantization is inherently lossy however i.e. the picture quality is diminished because of the loss of some data. This is customarily done by a process of rounding, truncation, or some other irreversible, nonlinear process of information destruction. Quantization is a necessary precursor to digital processing, since the image intensities must be represented with a finite precision (limited by word length) in any digital processor. In general, quantization can be classified into Scalar quantization (SQ) and vector quantization (VQ). In SQ, the input is processed individually to produce the output, while in V Q , the inputs are grouped together into vectors and processed to give the output [28].

1. Scalar Quantization

Scalar quantization is the process of converting the continuous value of the measurements to one of several discrete values through a non-invertible function. It is a single symbol method for the lossy coding of an information source with real-valued outputs [28]. A scalar quantizer followed by variable-length lossless coding (entropy coding) can perform remarkably well, which makes this method popular in applications where implementation complexity is a decisive factor.

2. Vector Quantization (VQ)

Vector quantization (VQ) is based on the principle of block of symbols used to represent the coding. It is a fixed-to-fixed length algorithm. A VQ is nothing more than an approximator. The idea is similar to that of ``rounding-off" (say to the nearest integer) [28]. The output of the vector quantization is also lossy. The performance of VQ are typically given in terms of the signal-to-distortion ratio (SDR):

$$\mathrm{SDR} = 10\log_{10}\left(\frac{\sigma^2}{D_{ave}}\right) \text{ in dB}$$

where σ^2 is the variance of the source and D_{ave} is the average squared-error distortion. The higher value of SDR shows that performance of the compressed image is better.

3. Quantization for DCT

Quantization is achieved by dividing each element in the transformed image matrix D by the corresponding element in the quantization matrix, and then rounding to the nearest integer value. Quantization is performed according to the following equation:

$$C_{i,j} = \text{round}\left(\frac{D_{i,j}}{Q_{i,j}}\right)$$

where $C_{i,j}$ are the quantized elements, $D_{i,j}$ are the DCT coefficients and $Q_{i,j}$ are the value from a quantization table. The quantized values are rounded off and then normalized by the quantizer step size. The larger the quantization coefficient, the more data is lost. Because of the rounding, one may get a lot 0's and the resulting coefficients contain a significant amount of redundant data. The following Huffman compression will remove the redundancies, resulting in smaller JPEG data.

4. Quantization for DWT

After applying the forward Discrete Wavelet Transform (DWT) to the 2-D image, the wavelet coefficients are quantized either scalar or vector based technique [27]. The quantization process reduces the precision of the coefficients. In JPEG2000 standard, a scalar quantizer is used and it is defined as:

$$q_b[n] = \text{sign}(y_b[n])\lfloor\frac{|y_b[n]|}{\Delta_b}\rfloor$$

Where Δ_b is the quantization step size, and $y_b[n]$is the transform coefficient for subband **b**. The quantization process is lossy, unless the coefficients are integers as produced by the LeGall 5/3 tap filter. In the case where the coefficients are integers the quantization step size is set to 1, which means that no quantization is performed and the coefficients remain unchanged.

V. SYMBOL ENCODERS AND ENTROPY CODING

This section focuses on the essential ways of compression by utilizing the distinctive types of methodologies and techniques, for example, variable-length codes, run-length encoding, dictionary-based compression etc.

1. Run-Length Coding (RLE)

RLE is one of the simplest data compression techniques. In light of the correlation among neighboring pixels, there are arrangements of rehashed and repeated pixels in a digital image and picture. It consists of replacing a sequence of identical symbols by a pair containing the symbol and the run length. It is used as the primary compression technique in the 1-D of the JPEG image compression standard [26]-[30].

2. Shannon-Fano Coding

In the late 1940s, Shannon and Fano discovered a compression method that depends on the appearance probabilities of source symbols in a message which is a sequence of source symbols. Their technique is known as Shannon-Fano coding. The fundamental thought behind of Shannon-Fano coding is utilizing variable length of bits to encode the source images as per their probabilities [26]-[30]. The more frequent the appearance of a symbol, the shorter the code length. The Shannon-Fano algorithm is as follows:

Step1: Sort the source symbols with their probabilities in a decreasing probability order.

Step 2: Divide the full set of symbols into two parts such that each part has an equal or approximately equal probability.

Step 3: Code the symbols in the first part with the bit 0 and the symbols in the second part with the bit 1.

Step4: Go back to Step 2, continue the process recursively for each of two halves until each subdivision contains only one symbol.

Shannon-Fano coding is the first successful compression method addressing the problem of the optimum source coding methodology.

3. Huffman Coding

In 1952, D.A. Huffman built up and implemented a coding procedure that creates shortest possible average code length given thesource symbol set and associated probabilities [11]-[14]. The shortest average code length is achieved by Huffman coding. It is also called as variable length coding (VLC) due to assigning variable-length code words to each symbol.

The Huffman algorithm is appeared as follows:

Step 1: List the probabilities of the source symbols, and produce a node set by making these probabilities the leaves of a binary tree.

Step2: Take two nodes with the two smallest probabilities from the node set, and generate a new probability which is the sum of these two probabilities.

Step3: Produce a parent node with the new probability, and mark the branch of its top (or left) child node as I and the branch of its bottom (or right) child node as 0, respectively.

Step 4: Update the node set by replacing the two nodes with the two smallest probabilities for the newly produced node. If the node set contains only one node, quit. Otherwise go to Step 2.

4. Lzw (Ziv-Lemple) Coding

It is a dictionary based coding and one of the most frequently used compression techniques. By constructing a dictionary, a message, which is a sequence of input symbols, can then be encoded as a sequence of reference entries to the dictionary.

LZW Compression Algorithm is given below:

Step 1: Create the first entry in the dictionary by adding the empty entry (a blank entry) to the dictionary and set the entry index of the empty message in the dictionary to n.

Step 2: Add additional 256 one-byte code words assuming the byte length is 8.

Step 3: Read one byte b at a time from a message to be encoded. If the word <n, b> is found in the dictionary, then update n as the reference entry index of the word <n, b>. Otherwise, transmit (or store) n. If the dictionary is not full, then add the word <n, b> into the dictionary. Update n as the reference entry index of the byte b.

Step 4: Repeat Step 3 till the whole message is encoded and transmitted (or stored).

Note: The word <n, b> is the nth entry in the dictionary followed by the byte b.

5. Arithmetic Coding

In previous part, we talked about the dictionary based Ziv-Lemple coding. In dictionary based coding, a message is represented as a sequence of dictionary indices [11]-[15],[28]-30]. A message can be encoded in many different ways. Arithmetic coding is another way to encode a message. In arithmetic coding, a message is encoded as a real number in an interval from zero to one. Arithmetic coding serves a vital part in imaging benchmarks, for example, JBIG and JPEG.

There are two fundamentals in arithmetic or number juggling coding: the probability of a symbol and its encoding interval range. The probabilities of source symbols determine the compression efficiency. They also determine the interval ranges of source symbols for the encoding process. These interval ranges are contained within the interval from zero to one. The interval ranges for the encoding process determine the compression output.

There are a few issues in arithmetic coding which the user may as of now notice that since there exists no single machine having an infinite precision, "underflow" and "overflow" are the obvious problems for the real world machines. The vast majority of these machines have a 16 bit, 32 bit or 64 bit precision or accuracy. Secondly, an arithmetic coder produces only one codeword, a real number in the interval [0, 1), for the entire message to be transmitted. We cannot perform decoding process until we received all bits representing this real number. Thirdly, arithmetic coding is an error sensitive compression scheme. A single bit error can corrupt the entire message.

These problems have been addressed by many researchers, and various schemes have been proposed. For instance, we can use a scaling process to solve the "underflow" and "overflow" problems.

6. Predictive Coding

Predictive coding is used to remove the mutual redundancy that exists between the successive pixels. Based on a sequence of reproduced pixels with an estimation rule. a pixel value can be predicted to replace the current pixel. This is the principle and rule behind the predictive coding. If the current reproduced pixel is taken as the sum of the predicted pixel value and the quantized error value between the current pixel and the predicted pixel, the prediction method is called differential pulse code modulation (DPCM). Since the prediction exploits the local correlation among the neighboring pixels. the predicted error can be encoded in fewer bits comparing to encoding the current pixel directly. Thus, in DPCM, rather than directly encoding the current pixel. the predicted error is encoded. The fact that DPCM utilizes the local correlation to reduce the redundancy in an image gives it an advantage over directly encoding the current pixel, which does not make use of the local correlation.

7. Subband Coding

Subband coding technique works based on decomposition of the source representation in the frequency domain into relatively narrow subbands [11]-[17]. Source coding without this frequency band decomposition is sometimes called fullband coding. In subband coding, since each of these bands has its own statistics, subjectively superior performance can be achieved over full band coding through an appropriate bit allocation strategy among the subbands. In the other words, subband coding does better resource allocation than fullband coding. In the case of image compression, subband coding puts more effort into the frequency bands where image activity is apparent by allocating more bits to these bands. A popular approach for subband coding is to use linear phase quadrature mirror filters (QMF's) to divide the full band into subbands. When channel noise and quantization noise are absent, using QMF's can result in near perfect reconstruction of the input signal without aliasing.

8. Differential Coding

Differential coding techniques explore the interpixel redundancy in digital images. The basic idea consists of applying a simple difference operator to neighboring pixels to calculate a difference image, whose values are likely to follow within a much narrower range than the original gray-level range [14]-[16]. As a consequence of this narrower distribution – and consequently reduced entropy – Huffman coding or other VLC schemes will produce shorter code words for the difference image.

VI. STILL IMAGE COMPRESSION STANDARDS

During the last two decades, a wide assortment of image compression framework has been proposed for both lossy and lossless for diverse applications by the computer scientists, mathematician, scholastic and insightful investigators. Distinctive sorts of image compression standards and benchmarks, for instance, JPEG, JPEG-2000, JPIP,, JPEG-LS and so on, have been utilized for the DICOM system. JPIP (JPEG 2000 Interactive Protocol) is a contemporary standard which is used for growing need to access medical images and therapeutic pictures fast while enabling and empowering interoperability in clinical and radiological framework [27]- [30].

It is remarkable that the DCT-based JPEG benchmark has been the compression standard of choice for many years but in recent years this has been eclipsed and overshadowed by the new JPEG2000 standard which is a wavelet based structure. The following sections start by investigating image compression techniques and systems, particularly JPEG. Accordingly, the JPEG2000 standard will likewise be investigated in point of interest. This will help to better understand and comprehend the reasons why wavelet transforms have become the transforms of choice for many image processing applications.

1. JPEG

The JPEG is a still image compression standard which was developed jointly by the International Organization for Standardization (ISO), the International Telecommunications Union (ITU) and the International Electrotechnical Commission (IEC) for audio, image, and video for both transmission and storage of digital products. Since the mid 1980s, members from both the ITU and the ISO have been working together to establish a joint international standard for the compression of grayscale and color still images [2]-[4]. This effort has been known as JPEG, the Joint Photographic Experts Group. (The “joint” in JPEG refers to the collaboration between ITU and ISO).

2. JPEG 2000

JPEG 2000 makes use of several advances in compression technology to deliver superior compression performance and provides many advanced features in flexibility, adaptability and scalability. JPEG 2000 frameworks functionalities outperform its predecessor because it uses the discrete wavelet transform (DWT) in place of the discrete cosine transform (DCT) of JPEG. The new demarcations of JPEG 2000 are JPSEC, JPIP, JP3D, and JPWL which deal with security, interactive protocols, multidimensional data sets and wire-less applications, respectively. These new divisions were designed to address standardization needs of specific application areas to which the rich set of technology from JPEG 2000 apply [28].

JPEG 2000 has seen successful adoptions in many areas of multimedia computing, for instance, digital cinemas, information security applications, video surveillance, defense imaging, remote sensing, medical imaging, digital culture imaging, broadcast applications, 3-D graphics, etc.

3. JPEG-LS

The JPEG-LS standard addresses both lossless and near-lossless compression of 2D images. It is based on a simple non-linear predictor, followed by a context-based entropy coder, and uses a quantizer in the prediction loop for near-lossless compression [27]. Although this standard has not been developed specifically for medical applications, its low complexity and good performance make it suitable for spectral image compression. In several papers a “differential” JPEG-LS algorithm is used for compression of 3D images, which simply takes differences of adjacent bands and encodes them using JPEG-LS. To maximize coding efficiency, the same principle can be applied to spatial-spectral slices, with the difference being taken in the remaining spatial dimension.

4. JBIG

JBIG (Joint Bit level Image Experts Group) is binary image compression standard that is based on context-based compression where the image is compressed pixel by pixel [28]-[30]. The pixel combination of the neighboring pixels (given by the template) defines the context, and in each context the probability distribution of the black and white pixels are adaptively determined on the basis of the already coded pixel samples. The pixels are then coded by arithmetic coding according to their probabilities. The arithmetic coding component in JBIG is the QM-coder.

5. Importance of the Standardization Process

Image coding is a stand out amongst the most well known fields of exploration and investigation since the advent of ubiquity of broadband networks (wired and wireless) in modern times. Researchers are attracted to image coding research as it finds diverse applications, for example, image science, digital signal processing, information theory, and systems concepts [25]-[30]. The industry also sees the attractiveness of imaging as a significant market potential such as high-resolution imagery, digital libraries, cultural archives, high-fidelity color imaging, Internet applications, wireless, medical imaging, digital cinemas, etc., requires additional, enhanced functionalities from a compression standard.

The first and premier target for creating standards in technology is to ensure consistence in interoperability among the various implementations so that applications/users will benefit from uniformity in functionalities and features when the advancement is applied. In the standardization process, there are basically two methodologies are employed, for instance, formal standards managed by organizations such as ISO/IEC and ITU-T and industry benchmarks oversaw by an industry consortium. Both procedures have their relative advantages – the formal standard technique tends to be all the all the more encompassing, complete, while the business consortium based standard strategy tends to be more specific and barely engaged [27],[28][30].

VII. CONCLUSION AND FUTURE SCOPE

In this paper, we have talked about the state of the art image compression for still images and pictures in spite of the way that it has been examined and thought comprehensively. We have explored and inspected an assortment of strategies, frameworks and algorithms that have been proposed most recently and pointed out their intrinsic likenesses and dissimilarities. We have called an attention to some of the measures that are utilized to assess compression performance and showed that the state-of-the-art has improved over the years, albeit not substantially. Therefore, efficient image compression techniques have to be established based on transformation schemes and efficiency of the encoding plan. This motivates us to analyze the problem of image compression and to examine the issues further in an effort to understand whether we have accomplished some hypothetical purposes of constrainment.

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