Evaluation of Lossless Compression Technique

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***Abstract*— Growth of internet and explosive development of mobile communications has given high demand to multimedia applications. Data explosion and the need for real time processing has resulted in requirements like large disk space and reduced transmission time. These key requirements have given rise to data compression technology. Data compression is a science of representing information in a compact form. The key factor in compression is to remove redundancy of data present within a data set in order to reduce its size without affecting the essential content in it. Lossless compression format is basically defined by characteristics such as bit rate, PSNR etc. This paper is an effort to evaluate different lossless compression techniques available which are used in applications where integrity of the data is maintained with high quality.**

***Index Terms*— DFT, DWT, Entropy, Evaluating parameters, JBIG, Lossless compression, PSNR, Redundancy model**.

I. Introduction

DATA Compression [1] is concerned with encoding digitized text, audio, image or video signals with minimum number of bits so that the amount of bits transmitted can be increased and carried on a lower-capacity communication system, taking up less storage space and hence requires less bandwidth for efficient transmission. In sensor networks [2]; compression is needed to save energy consumption in high-end servers and data centers. Telemedicine technology [3] supports the transfer of pathological and imaging reports of patients across the telemedicine networks. An uncompressed medical image, say 800 x 800 pixel will need 64 x 10^4 bytes, i.e. 0.64 MB. If 1000 images of such size are to be stored, we need 640 MB. A file of that size will take longer time to transmit in a network to remote medical centre and will take huge memory to store volumetric data for diagnosis. In case of digital watermarking [4], where high accuracy is being demanded in remote sensing and military imaging. In such situations we need to compress the image, with reduced number of bits, without distorting the original image. Lossless and Lossy compressions [5] are the two strategies of compression. Lossless compression is used in applications that require an exact reconstruction of the original data. Lossless compression algorithms typically exploit data redundancy, and aim to increase effective data density, allowing the application to get back the original data in its entirety. This technique is generally used for text files, legal records, high - resolution television and medical images [6], where losing words or data may cause a problem. On the other hand, Lossy compression is used when the user can tolerate some difference between original and reconstructed representation of data. It transforms and simplifies the data in a much larger reductions in file size than lossless compressions. But it can distort the file's content due to the higher reduction.

In the proposed research paper, Section II briefly discusses about the compression technical challenges and strategies. Section III discusses the technical framework for lossless compression and their major components. Section IV focuses on various Evaluation Criteria. Section V briefly compares the lossless compression techniques for different data followed by concluding remarks of the paper are presented in Section VI

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II. Compression-Technical Challenges

Compression plays a centric role in reinforcing and enabling applications, where enormous amount of data get maneuvered every instant. Off the different types of data being maneuvered, different applications have different requirements for data compression schemes. Choosing an efficient and cost-effective compression algorithm to provide an optimal solution is very challenging and complex and thus involves performing tradeoff analysis on various factors which are important to the application. Some of the challenges in the compression are:

A. Compression Efficiency:

High compression efficiency provides high data rates. It is required in the applications like video-on –demand, streaming multimedia, video conferencing etc.

B. Resolution

Higher the compression ratio, lesser the space required for the compressed data, but they fail to get high resolution. Application like HDTV, medical imaging mobile data requires high quality images but they require higher bandwidth.

C. Error Resiliency

Applications like satellite imaging as in [7], remote sensing, requires robust error resiliency as they uses air transmission methods.

D. Power Consumption

Low power consumption is ensured in the battery operated devices used in the application like mobile phones, wireless

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sensor network [8]. This requires low computation memory for encoding and decoding.

E. Data Rates

A high data rate requires high compression efficiency and high computational memory and low latency. It is highly needed in networks to download files.

Depending upon the challenges in the application, compression relies on two main strategies. The key factor in compression is to remove redundancy of data which is present within a data set to reduce its size without affecting the essential information of it. Redundancy [9] can be of different types:

1) Spatial redundancy: It utilizes the correlation between neighboring pixel values in case of grey scale image.

2) Spectral redundancy: Correlation between different color planes or spectral bands in case of color image.

3) Temporal redundancy: Correlation between adjacent frames in a sequence of images in case of video.

4) Coding redundancy: It utilizes the probability distribution associated with the occurrence of the symbols. This can be removed if fewer bits (short code) are assigned to the more probable gray scale values and more bits (longer code) to the less probable ones. This process is called as Entropy coding.

5) Psycho visual redundancy: This takes into account the properties human vision. Human eyes do not respond with equal sensitivity to all visual information. Higher spatial frequency components information has less relative importance as compared to lower frequency information. This information is said to be psycho visually redundant.

Digital data can be compressed in different domains [9] - Spatial domain, Frequency domain or Spatio-Frequency domain. Compressing a digital data in frequency domain is advantageous as it can achieve better compression ratio as compared to its spatial domain counterpart. However, spatial domain image compression methods are computationally less complex as compared to frequency domain compression. There are different compression techniques which are summarized in Table I.

Depending upon the application one or a combination of the compression techniques [5] can be chosen. Scalar Quantization includes mapping of regions of a data set onto elements of a smaller one and vector quantization includes mapping of multidimensional space into a smaller set of data; transform of the input into a different form is done in transform coding where compression is achieved by dropping certain terms without much qualitative loss in the output. Fractal compression associates a family of functions, which have fixed points that may be found in an iterative way without unduly long convergence, with data point values. JPEG, MPEG and MP3/AAC are widely applied compression standards that are used for still images, videos and audio data respectively.

TABLE I
COMPRESSION STANDARDS [5] [3]

Lossy Compression	Lossless Compression
Scalar Quantization (Uniform / Non Uniform)	Huffman
Vector Quantization	Adaptive Huffman
Differential or Predictive coding	Lempel-Ziv 77 / 78
Transforming coding (DCT,FFT)	Lempel-Ziv-Welch (LZW)
JPEG (Wavelet)	RLE
MPEG	Arithmetic Coding
MP3/AAC	Burrows Wheeler
Fractal Compression	JBIG

DCT = Discrete Cosine Transform, FFT = Fast Fourier Transform, JPEG = Joint Photographic Expert Group, MPEG = Moving Picture Experts Group, MP3 = MPEG Audio Layer 3, AAC = Advanced Audio Coding, RLE = Run Length Encoding, JBIG = Joint Bitonal Image Group.

III. LOSSLESS COMPRESSION – TECHNICAL FRAMEWORK

Lossless image compression has been a significant issue in recent years due to the increasing demand for storing huge amounts of high quality multimedia data in a small storage. Applications like medical imaging, satellite imagery, FAX transmission etc. uses lossless compression techniques to store and transmit data. As presented in Fig.1, the basic principle of Lossless compression algorithm is that any non- random file will contain duplicated information that can be reduced using some modeling as presented in [5].

This model determines the probability of a bit or character appearing in the data set. It assigns shortest code to the most common data and longer code for uncommon data. Such coding techniques are called entropy coding [5]. Lossless

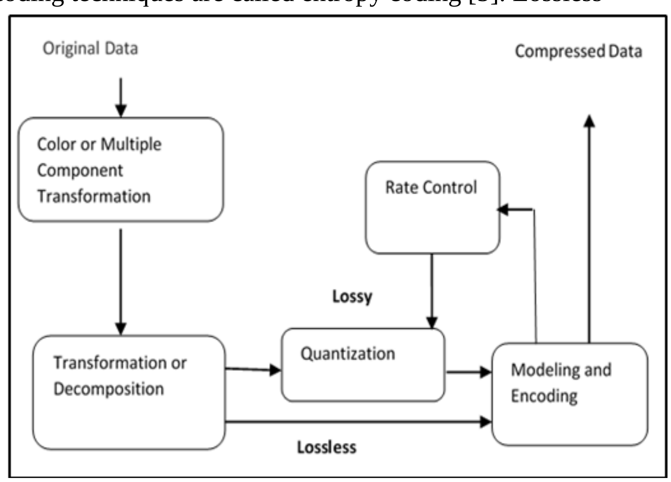

Fig. 1 Basic Structure of Lossless Compression

Compression uses various Modeling and coding techniques which is summarized in Fig 2.

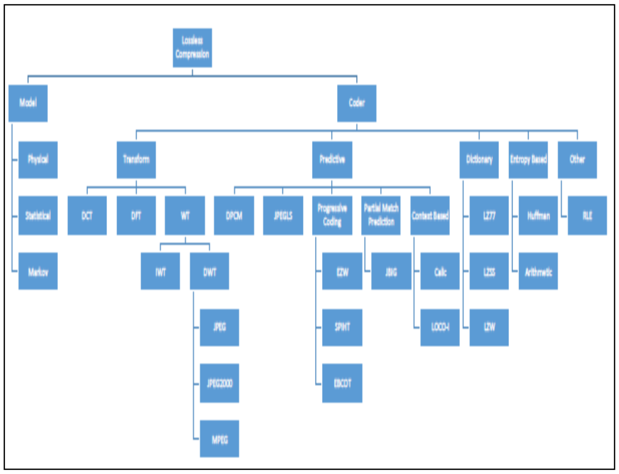

Fig. 2. Lossless Compression Techniques

DCT- Discrete Cosine Transform, DFT-Discrete Frequency Transform, DWT-Discrete wavelet Transform, IWT- Integer wavelet Transform, DPCM-Differential pulse code modulation , JPEG-LS- JPEG lossless, JBIG- Joint Bi-Level Expert Group, RLE-Run length Encoding , LZW-Lempel Ziv Welch, EZW-Embedded Zero Wavelet Coding, SPIHT-Set Partition In Hierarchical Tees, EBCOT- Embedded Block Coding using Optimized Truncation.[5],[24][25]

IV. Evaluation Criteria

There are various parameters to evaluate compression, like complexity of the algorithm, memory required to implement the algorithm, how fast the algorithm performs on a given machine (compression speed), the amount of compression (compression ratio), how closely the reconstruction resembles the original (image quality), reduced energy consumption etc. Lossless compression should compress the bits faster while keeping all the information of the source. It follows a scheme that can encode the output of the source with an average number of bits equal to the entropy of the source. Entropy [5] can be calculated as.

$$H = -\sum_{i=1}^{m} P\,(si)\log_2 P(si) \qquad (1)$$

Where P s(i) is the probability of occurrence of i th set.

The main parameters used to select a lossless compression technique are:

A. *Compression Ratio (CR)*

It is defined as the ratio of number of bits in the original image to the number of bits in the compressed image. High compression ratios are desired. It is represented as 5:1, if 1MB file is compressed to 200KB file. With lossless compression, limited amount of compression is achieved.

B. *Image Quality (IQ)*

1) *PSNR:*

The quantity which measures the quality of the Reconstructed image compared to the original image is called Peak Signal to Noise ratio (PSNR), measured in decibel(dB) and is defined as :

$$PSNR = 20\log_{10}\left(\frac{255}{\sqrt{\text{MSE}}}\right) \qquad (2)$$

where MSE is Mean Squared Error and 255 is the maximum possible pixel value in 8 bits

2) *MSE:*

MSE is defined as cumulative square of the difference between original and reconstructed image. It is given as

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[\,\mathrm{I}(i,j) - \hat{\mathrm{I}}(i,j)]^2 \qquad (3)$$

where I is original image, Î is approximation of reconstructed image. m and n are dimensions (width and height) of the image. Thus lower the MSE, higher is PSNR for an image. PSNR in the range 20-40dB is always preferred for a lossless compression. PSNR value also decreases after multiple compressions. There is a conflict between the higher compression ratio and the quality of the compressed image. Hence optimum CR with high PSNR is desired in lossless compression.

C. *Compression Rate*

It is defined as the average number of bits required to represent a single sample (or pixel). It is measured in bits per pixel(bpp) for coding an image.

D. *Distortion*

It is defined as the difference between the original image and the reconstructed image. In lossless compression distortion toleration is always zero for any application. There is a trade off between minimizing the rate and keeping the distortion small. Rate distortion theory is the entropy theory.

E. *Coding Complexity and Compression Speed*

The coding complexity of a compression algorithm is a measure of computational requirement in terms of computational requirement in terms of software (instructions per second) and hardware (low power). Complex algorithms can reduce the compression speed.

F. *Latency*

Latency is the time taken to compress, send, decompress and display a file. The more advanced the compression algorithm, higher the latency.

V. Comparative Study of Various Lossless Compression Techniques

There are many ways to characterize the data. Different characterizations will lead to different compression schemes. Lossless compression can be applied to various formats of data like text, image, video, audio etc.

A. *Text Compression*

Text essentially consists of words and punctuations forming up sentences. These words belong to standard list called as Dictionary. Also based on statistics [10] of usage, average word length in language can be considered as a set of binary strings. Hence we have different approach to compress text data. They are as follows

1) Dictionary Based: Dictionary based coding can be static or dynamic. In static coding, dictionary is fixed during encoding and decoding processes. In dynamic dictionary coding, the dictionary is updated on fly. It uses LZW algorithm. During the compression they build a dictionary from the components appeared in the past and uses it to reduce the sequence length if the same component appears in the future. LZW is widely used in computer industry and is implemented as compress command on UNIX. It takes long time for adaptation; hence they tend to depend on the size of the source file. The two major versions of the Lempel–Ziv algorithms: LZ77 [11] and LZ78 [11]. LZW is the LZ78 based algorithm.

2) Run Length Coding (RLE): This is very simple compression method [10] used for sequential and repetitive data. It replaces sequences of identical symbol called runs by shorter symbols. It is represented by a sequence {Vi, Ri} where Vi and Ri refers to the length and occurrence of the symbol respectively. In the data 'AAAABBBBBCAADDDD' with 16 bytes can be coded by ten byte code '4A5B1C2A4D' yielding a compression ratio of 1:2.

3) Entropy Based Coders: An Entropy based coder allocates a number of bits to a code word proportional to an information value of the code word. Huffman coding [12] invented by David Huffman is based on statistical occurrence of frequencies. The symbols that occur more frequently are assigned a smaller number of bits, while the symbols that occur less frequent are assigned a relatively larger number of bits. It is a prefix code. It uses a variable probabilistic coding method to create a tree. The aim of Arithmetic Coding [13] is to assign an interval to each potential symbol. Then a decimal number is assigned to this interval. The algorithm starts with an interval of 0.0 and 1.0. After each input symbol from the alphabet is read, the interval is subdivided into a smaller interval in proportion to the input symbol's probability. This subinterval then becomes the new interval and is divided into parts according to probability of symbols from the input alphabet. This is repeated for each and every input symbol.

4) Statistical Based Techniques [14]: In statistical modeling the compression is based on statistical redundancy. It uses probability of occurrence of the data to do compression. The two main types are Prediction by partial matching algorithm and BWT. In Prediction by partial matching (PPM) method [14], main idea is to gather the frequencies of symbol occurrences in all possible contexts in the past and use them to predict probability of occurrence of the current symbol Xi. This probability is then used to encode the symbol Xi with Arithmetic coder. In 1994, Burrows and Wheeler [15], [16] presented a data compression algorithm based on the Burrows–Wheeler transform (BWT). It works in block mode as compared to the other, which works in streaming mode. It is based on sorting of the sequences based on some context. They are called as successive contexts because the characters that precede the contexts are considered. These characters can be used as input for another algorithm to achieve good compression ratios. It seems to be a better compression compared to PPM. But it suffers from time complexity.

5) JBIG: The JBIG standard [17] is the new international standard for bi- level image compression used in FAX transmission. The JBIG standard can be viewed as a combination of two algorithms, a progressive transmission and a lossless compression algorithm. It performs adaptive compression that is both the encoder and decoder collects statistical information of the transmitted image from the pixels transmitted, in order to predict the probability for each next pixel being either black or white. In [18], Text compression is done with JBIG2 compression technique, allowing two encoding strategies, SPM (Soft Pattern Matching) and PM&S (Pattern matching and substitution). It is concluded that SPM-based JBIG2 achieves better CR of 25.6 over PM&S, whose CR is 23.5.

B. Video and Image Compression

All video data takes up a lot of space. Video compression technologies are about reducing and removing redundant video data so that a digital video file can be effectively sent over a network and stored on computer disks. Usage of standard compression techniques ensures compatibility and interoperability. Video compression standards include Motion JPEG, MPEG-4 and H.264. Video codecs (encoder/decoder) are a pair of algorithms that work together. They are not interchangeable but it is possible to implement many different algorithms in the same software or hardware, which would then enable multiple formats to coexist. Image compression involves intra frame coding wherein data is reduced within an image frame by removing unnecessary information that may not be noticeable to the human eye whereas Video compression algorithms use inter frame prediction to reduce data between a series of frames. Different transform coding techniques used in image and video are as follows:

1) DFT and DCT: DFT is the transformation of the discrete signal of time domain into its discrete frequency domain representation. DCT (Discrete cosine Transformation) is a simple and basic technique to transform an image from spatial domain to frequency domain. Well-known JPEG (Joint Photographic Experts Group) is based on DCT is lossy compression techniques with relatively high compression ratio which is done by exploiting human eye perception. But suffers from blocking artifacts [19].The DCT is more efficient in concentrating energy into lower order coefficients than DFT.

2) WT: Wavelet based compression techniques have

become more popular because they provide exceptional image quality at high compression rates. It avoids blocking artifacts, better matched to the HVS (Human Visual System). It is efficient at low bit rates as compared to DCT. DWT (Discrete Wavelet transform) and IWT (Integer Wavelet Transform) are two important types of wavelet based compression. IWT technique is a lossless compression based on an integer wavelet filter called biorthogonal 3/5. The IWT, construction using lifting is done in the spatial domain, contrary to the frequency domain implementation of a traditional wavelet transform. JPEG 2000 is lossless mode runs really slow and often has less compression ratios on artificial and compound images. Various schemes under this technique are: Lossless JPEG [20], JPEG-LS [21], progressive Transmission [22, 23] etc. Predictive coding and DWT has given rise to many lossless schemes. This technique follows some prediction about the neighbor pixels to get the next pixel.

C. *Audio Compression*

Analog audio signals are converted into digital audio through a sampling process and then compressed to decrease the size for efficient transmission and storage. The conversion and compression is done using an audio codec, an algorithm that codes and decodes audio data. The bit rates most often selected with audio codecs are between 32 kb/s and 64 kb/s. There are various audio codecs to support different sampling frequencies and levels of compression. Sampling frequency refers to the number of times per second a sample of an analog audio signal is taken and it is defined in hertz (Hz). Higher the sampling frequency, better the audio quality and the greater the bandwidth and storage needs. With increased network bandwidth, lossless codec like Dolby, True HD are becoming popular.

VI. CONCLUSIONS

This paper focuses on various challenges in compression of different data for different applications and various techniques for compressing data in different domains. In Text compression, two techniques were discussed; Dictionary based and Statistical based. In case of dictionary based approach LZW outperforms LZ77 and LZ78 algorithm. In case of statistical method, Arithmetic coding provides better lossless compression as compared with RLE or Huffman coding. In case of DWT based compression, JPEG-LS is better than lossless JPEG w. r. t tradeoff between the image quality and compression ratio. In case of image compression using progression transmission, SPIHT method creates two different types of space zero tree, and uses wavelet coefficients more efficiently than EZW, so that it has higher efficacy than that of EZW encoder. Thus the advantage of compressed domain operations is that they can often be performed many times faster than their spatial; domain counterparts, and that they process less data, which increases locality and lowers bandwidth requirements. Higher compression levels may also introduce more latency or delay, but they enable greater savings in bandwidth and storage.

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