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Image Compression Techniques: A Comparative Study

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Abstract

Digital images are required to store a large among of storage space in digital computers. Nowadays, computer system is very capable to process digital images with high resolution quite easily. The transmission of huge data needs more time to transfer over network channel. Thus, time and space are two fundamental components of computing. In the field of digital image processing, image compression is one of the most popular and commercially successful technologies, which compress the size of data according to express a given quality of information. In addition, digital images store three types of information such as redundant, useful and irrelevant. In this study, various compression techniques have been discussed. Image compression techniques are divided into two categories such as lossless and lossy image compression. Both techniques have been discussed with suitable examples and block diagrams.

Keywords: *Image compression, lossless, lossy, JPEG*

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INTRODUCTION

Image compression is an important application of digital image processing. Digital images store a huge amount of space in digital computers. Image compression is used to reduce the memory requirements as well as transmission cost. Therefore, image compression is one of the popular techniques which reduce the size of data according to display of a given quality of information. An encoder receives an original image and then converts into binary numbers which are called bit-streams. On the other side, the decoder receives encoded data (bit-streams) and decodes them into decoded image [1].

Advantages of Image Compression

These are the following advantages of image compression [1]:

i. It reduces the communication costs as well as data storage requirements while transmitting the large volume of data over the network with the help of an effective bandwidth.
ii. It improves the quality of various multimedia presentation systems via limited data transmission rates.
iii. The speed of input-output functions in the computing device is extremely increased because of smaller representation of the data. For example, in the hierarchy storage system, the principle of data compression makes faster storage level, while decreasing the burden on input-output communication channels.
iv. It also reduces the cost of backup and recovery of data in the computing device by saving the large volume of databases into compressed forms.

Disadvantages of Image Compression

These are the following disadvantages of data compression [2]:

i. It decreases the reliability of database. A single bit error in the compressed data may generate incorrect data. For example, during the transmission of medical information via noisy communication network some burst errors are generated by communication channel that may destroy the transmitted data.
ii. With the disruption problem, the compressed data sets are generally different from original data sets.
iii. With the hardware and software implementation, an extra complexity required to produce data compression may decrease an efficiency of the system and

increase the system cost, especially in the field of very-large-scale integration (VLSI) implementation.

The idea behind image compression is to reduce or remove the redundancies that occupy more storage space as well as transmission time. The data redundancies do not carry any new type of information and thus have no contribution in improving the image quality.

Types of Image Compression

In general, image compression can be classified into two parts, namely, lossless and lossy image compression [3].

Lossless Compression

Lossless compression approach performs a perfect reconstruction and it does not lose any information during compression-decompression process. Therefore, it allows error free and reversible compression. In other words, it does not lose the perceptual quality of an image as well as preserves the image contents and allows lower compression ratios such as 1-3:1. In this approach, quantization process is not included, as a result of which the reconstructed data is completely identical to original data. The lossless approaches are applied on scientific data or text data because after decompression operation an output is expected identical to an original data. A little error in the output text may completely change the meaning. Various applications that require lossless technique are facsimile (FAX) transmission, medical imagery, business documents and satellite image compression, where any loss of information can lead to wrong diagnosis or prediction. However, in order to remove data redundancy, it focuses on especially spatial and coding redundancies. Arithmetic coding, Huffman coding, Run length coding and Differential Huffman coding are examples of lossless coding technique [4].

Lossy Compression

Lossy image compression technique is irreversible in nature which allows higher compression ratios such as 30-100:1. The lossy compression generates imperceptible difference between original and reconstructed data. The lossy compression algorithms are generally applicable where small loss of information is tolerable by human visual system (HVS) such as graphics, speech, images and videos etc. In case of removal of data redundancy, it focuses on especially spatial, coding and psycho-visual redundancies. Discrete wavelet transforms (DWT) and discrete cosine transform (DCT) are the examples of lossy compression techniques.

Hybrid Compression

Hybrid compression is the combination of both lossy as well as lossless compression within a single encoding block. The primary feature of hybrid compression is that it has advantages of both lossless and lossy compression. The hybrid compression ratio lies between lossless and lossy compression ratios.

JPEG Image Compression

Joint Photographic Expert group (JPEG) is one of the most widely used standards in image compression. It is a first international compression standard used in multilevel images such as color and gray scale in comparing with many lossless compression techniques. It is mostly used in digital cameras as well as images on web pages with JPEG format. Its popularity is mainly by its capability in maintaining a significant compression rate at acceptable image quality. The primary focus of JPEG algorithm is the removal of non-essential details that are psycho-visually not perceivable to HVS. Image transformation coding schemes de-correlate the pixel intensities in small spatial region (8×8 blocks) and pack the energy in a DCT coefficients [5, 6].

Figure 1 demonstrates the block diagram of JPEG model. According to Figure 1(a), JPEG compression model is based on three stages: in first stage, the whole image is divided into non-overlapping blocks with the size of 8×8 because mean squared error (MSE) is almost minimum for block size 8×8 and then applied discrete cosine transformation (DCT) on each block independently. In the second stage, the above

DCT coefficients are quantized with the help of quantization table and quantized values are converted into nearest integer value at the end, lossless compression coding technique such as entropy coding has been used to generate compressed data. On the other hand, the decompression procedure also has three stages such as decoding, de-quantization and inverse DCT (IDCT) as shown in Figure 1(b) [7].

TYPES OF LOSSLESS TECHNIQUES

Huffman Coding

Huffman coding one of the oldest approaches of data compression and was presented by David Huffman in 1952, this approach has been a principle of intensive research in digital image compression. This coding technique generates average length code given by source symbols and combines with the probability of occurrence of symbols. The codes produced by this coding method are called Huffman codes [8]. Huffman coding is based on building a binary tree that holds all characters in the source as its leaf modes, and with their corresponding character's probabilities at the side. Nevertheless, Huffman coding has been adapted by some commercial and important applications such as JPEG, MPEG and FAX machines.

Arithmetic Coding

Arithmetic coding technique has more flexibility and superior efficiency as compared to Huffman coding. It is especially useful for handling the source with small alphabets like alphabets with the highly skewed probabilities and binary alphabets. The important drawback of Huffman coding technique is to assign an integer codeword to every symbol individually. As an output, the size of bit rate cannot be less than one bit per symbol, otherwise; symbols are coded together (jointly). On the other hand, this compound symbol increases computation complexity and memory requirement. One more drawback of Huffman coding is that the framework of encoder and decoder is based on source statistical scheme. It follows with any modification in source statistical will also necessary to redesign the Huffman codes. Arithmetic coding technique is a lossless coding approach which does not deal with aforementioned drawbacks and has achieved higher compression efficiency compared to Huffman coding [9].

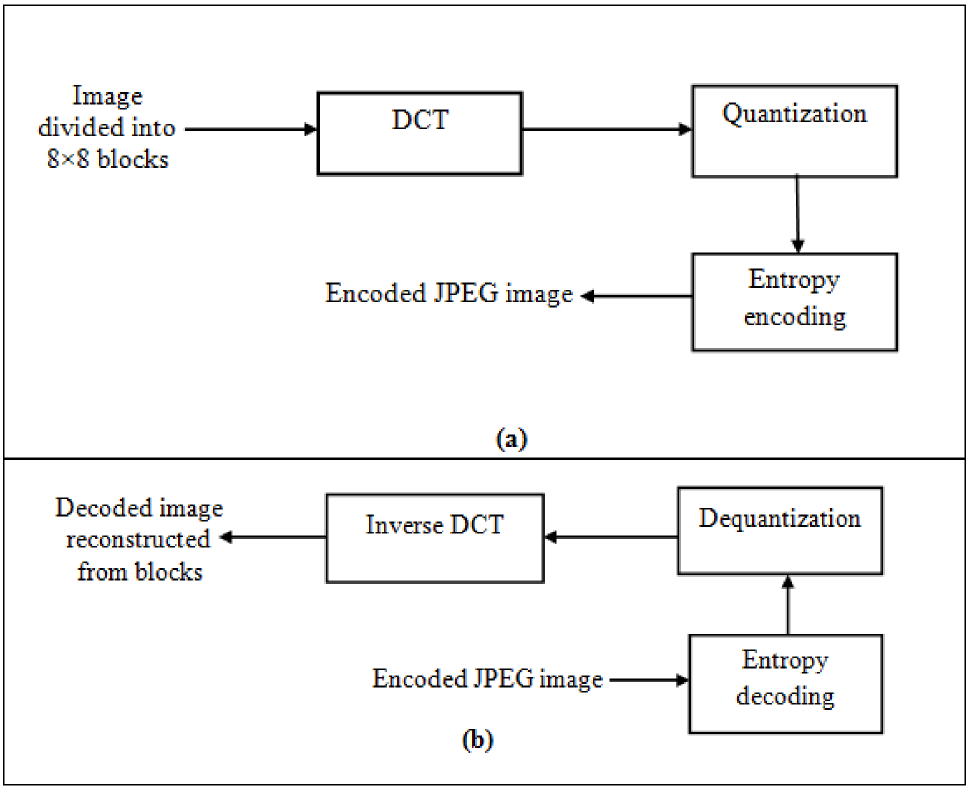

Fig. 1: *JPEG Image Compression Model.*

Lempel-Ziv Coding (LZW)

Arithmetic coding and Huffman coding techniques need a priori knowledge of statistical model as well as source symbol probability model. Sometimes, it is very difficult to select the source symbol model, particularly when different types of data such as natural, graphics and text images etc. are intermixed. A universal coding approach does not need a priori knowledge of source symbol models and statistical models. The dictionary based coding method has been proposed by Ziv and Lempal in 1977 and popularly called Lempal-Ziv Coding (LZC). There are various predecessors of Lempal-Ziv such as LZ77 and LZ78. Terry Welch made significant improvement to this method in 1984. Therefore, it is known as LZW (Lempel-Ziv-Welch). LZW scheme is used in several applications such as GIF image files, computer commands (UNIX Compress), text sources and others [10].

Run Length Coding (RLC)

In this coding scheme, if the data D is repeated many times in an input stream, replace N occurrences along with a single value ND. The two adjacent pixels are highly correlated with each other in an image. In a smooth area of an image, the consecutive pixels are mostly identical or having less variation in intensity level. If the size of a run is long with identical pixels, it is very difficult to broadcast the run associated with a specific pixel values rather than the encoding of individual pixel value. RLC is the simplest technique to source coding for the long size of same data in a consecutive manner [11].

For example,

$D = 6\ 6\ 6\ 6\ 6\ 6\ 6\ 20\ 20\ 20\ 20\ 20\ 20\ 20\ 20\ 20\ 20\ 20\ 20\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 1\ 24\ 24\ 24\ 24\ 24\ 24$

D consists of long run of 6's, 20's 1's etc. In this way, data D is encoded as $(6\ 7)\ (20\ 12)\ (1\ 8)\ (24\ 6)$. To easily understand, a pair is shown in each parenthesis. First value indicates a pixel value and second value represents length of a run. RLC technique is also used in black and white (binary) images such as FAX which consist only two values, zero and one.

Table 1 demonstrates the comparison of various lossless image compression techniques.

TYPES OF LOSSY IMAGE COMPRESSION

Lossy image compression methods contain some loss of information and an input image that has been compressed by lossy methods commonly cannot be reconstructed or recovered completely. Lossy techniques are mostly adopted by multimedia applications because these applications require higher compression factor [12].

Predictive Coding

Predictive coding has been widely used in image compression. Prediction provides a compact description of data with the determination of error between data itself and information predicted from past observation. If prediction error is negligible or small then predicted data is similar to original input data. Predictive image coding techniques are used to exploit a high degree of correlation among adjacent pixels. This coding technique predicts the value of a given pixel based on the values of the neighboring pixels.

Quantization

Every DCT coefficient is mapped into a set of finite number of different values that is determined by compression factor. Moreover, to demonstrate the source output, reduce the size of distinct values into much smaller set through quantization. This can be determined by dividing every component (element) of DCT coefficient by corresponding component in 8×8 quantization matrix and calculating the results [13].

Discrete Cosine Transform (DCT)

DCT is generally used in transform coding methods, and was introduced by Ahmed in 1974, which is able to represent the de-correlation of an input data into data independent form [14]. It has ability to transform energy into few coefficients. Therefore, DCT has achieved tremendous popularity. Each pixel of an image is decomposed into 8×8 block. A 2-D DCT is implemented on every block of image to access 8×8 array of coefficients.

Wavelet Based Coding

The wavelet is a tool for decomposing an input signal data such as image into components to increase the resolutions; with the high resolution, a more detailed image is generated that improves the compression performance. Wavelet may be observed as "mathematical microscopes" that allow one to "zoom in" as well as "zoom out" of an image with different resolutions [1, 14]. In wavelet transformation, an input image is decomposed into sub-bands using separable median filters. The frequency content of an image is divided into two sub-bands such as low band and high band along with one direction and then along the other. This gives four versions of the image with different frequency contents.

Table 2 demonstrates the various lossy image compression techniques [15].

Table 1: *Comparison of Various Lossless Image Compression Techniques.*

Technique	Compression Rate	Remarks
Huffman Coding	Low compression rate	Based on mathematical calculation. Codewords are determined with probability distribution function.
Arithmetic Coding	Low compression rate	The optimal codeword length is obtained when the symbol probabilities are of the form of $^1/_2$ (integral power).
LZW Coding	Low compression rate	It replaces strings of characters with single codes. Compression occurs when a single code is output instead of a string of characters.
RLC Coding	Low compression rate	It is only effective when data sets have long sequence of a single repeated character.

Table 2: *Comparison of Various Lossy Image Compression Techniques.*

Techniques	Compression Rate	Remarks
Predictive Coding	Low compression rate	It generates worse reconstructed image quality as compared to transform coding schemes.
Quantization	High compression rate	Easily implementation of decoder. For large computational resources, it requires codebook training and construction. Generates edge degradation.
Transform Coding	High compression rate	It transforms image information from spatial to transform domain. Reconstructed image affected by various compression artifacts.

CONCLUSIONS

This study describes a comprehensive study of image compression techniques including lossless compression and lossy compression. Image compression has large number of applications in the area of multimedia such as used in video production, digital computers for publishing and printing etc. In addition, image compression has been used in video conferencing, FAX, satellite transmission, graphics, medical images, drawings, finger prints and multispectral images. Lossless compression is an error free technique which is used for some specific applications that need reconstruction of an original data, where as lossy compression algorithm is used where user can tolerate some loss of information. The primary objective of both schemes is to reduce the average bit rates without any loss of information.

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