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The State of the Art in Image Compression

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Abstract: In today's digital world information exchange is been held electronically. This transmission should provide efficiency in factors like transfer speed, cost, transmission errors etc. Image compression is minimizing the size in bytes of an image without reducing the quality of the image to an unacceptable level. It makes the transmission process faster, provides larger bandwidth and security against illicit use of data. This paper addresses the area of image compression as it is applicable to various fields of image processing. So Image compression is used to provide efficient transfer of data. This paper provides a basic introduction about image compression, and various types of image compression techniques.

Keywords: Image, Image compression techniques, Data redundancies, Compression ratio, Coding redundancy, Inter pixel redundancy

I. Introduction

A. Image

An image is essentially a 2-D signal processed by the human visual system. So, digital images are popular medium of transferring visual information. The signals representing images are usually in analog form. However for processing, storage and transmission by computer applications, they are converted from analog to digital form. A digital image is basically a 2-Dimensional array of pixels. A digital image obtained by sampling and quantizing a continuous tone picture requires an enormous storage [1]. As the use of information continue to grow in every sector, so too does our need for efficient ways of storing and transmitting large amounts of data.

B. Image Compression

With the rapid development of digital technology, the demand to preserve raw image data for further editing or repeated compression is increasing. In image processing, compression schemes are aimed to reduce the transmission rate for images, while maintaining a good level of visual quality. Compressing an image is significantly different than compressing raw binary data. General purpose of compression programs can be used to compress images, but the result is less than optimal. The reduction in image size allows more images to be stored in a given amount of disk or memory space.

Image compression addresses the problem of reducing the amount of data required to represent a digital image. This is done by taking advantage of these redundancies. An inverse process called decompression (decoding) is applied to the compressed data to get the reconstructed image. Image compression systems are composed of two distinct structural blocks: an encoder and a decoder. The need for an efficient technique for compression of Images ever increasing because the raw images need large amounts of disk space seems to be a big disadvantage during transmission & storage [1].

As the name indicates the original image can be perfectly recovered using the lossless compression techniques [2].Lossless compression involves with compressing data which, when decompressed, will be an exact replica of the original data. This is the case when binary data such as executables, documents etc. are compressed. They need to be exactly reproduced when decompressed. On the other hand, images need not be reproduced 'exactly'. An approximation of the original image is enough for most purposes, as long as the error between the original and the compressed image is tolerable. Lossless compression is preferred for archival purposes and often for medical imaging, technical drawings, clip art, or comics [Wiki]. The lossy compression is a compression technique that does not decompress data back to 100% of the original [3]. The lossy compression that produces imperceptible differences may be called visually lossless [2].

C. Data Redundancies

Compression is achieved by the removal of one or more types of the three basic data redundancies.

1. Coding Redundancy
2. Inter pixel Redundancy
3. Psycho visual Redundancy

1) Coding Redundancies

Coding redundancy is present when less than optimal code words are used. It is a type of coding that is always reversible and is usually implemented using look-up tables [3]. Our quantized data is represented using codeword. The codeword are ordered in the same way as the intensities that they represent; thus the bit pattern 00000000, corresponding to the value 0, represents the darkest points in an image and the bit pattern 11111111, corresponding to the value 255, represents the brightest points .If the size of the codeword is larger than is necessary to represent all quantization levels, then we have coding redundancy. An 8-bit coding scheme has the capacity to represent 256 distinct levels of intensity in an image. But if there are only 16 different grey levels in an image, the image exhibits coding redundancy because it could be represented using a 4-bit coding scheme. Coding

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redundancy can also arise due to the use of fixed-length codeword.

2) Inter Pixel Redundancies

This type of redundancy is sometimes called spatial redundancy; inter frame redundancy, or geometric redundancy [3]. Inter pixel redundancy results from correlations between the pixels of an image. The intensity at a pixel may correlate strongly with the intensity value of its neighbours. Because the value of any given pixel can be reasonably predicted from the value of its neighbours. Much of the visual contribution of a single pixel to an image is redundant; it could have been guessed on the bases of its neighbour's values. We can remove redundancy by representing changes in intensity rather than absolute intensity values. For example, the differences between adjacent pixels can be used to represent an image. Transformations of this type are referred to as mappings. They are called reversible if the original image elements can be reconstructed from the transformed data set.

3) Psycho Visual Redundancies

Psycho visual redundancy is due to data that is ignored by the human visual system .The significant improvements possible with quantization that takes advantage of the peculiarities of the human visual system. The method used to produce this result is known as improved gray-scale (IGS) quantization. It recognizes the eye's inherent sensitivity to edges and breaks them up by adding to each pixel a pseudo-random number, which is generated from the order bits of neighboring pixels, before quantizing the result.

D. Compression Ratio

Compression is the process of coding that will effectively reduce the total number of bits needed to represent certain information. Hence number of bits before and after decides ratio. Compression ratio is calculated by following formula.

$$\text{Compression ratio} = \frac{\text{No of bits before compression}}{\text{No of bits after compression}}$$

II. Image Compression Techniques

The image compression techniques are broadly classified into two categories. This classification is done by depending on whether or not an exact replica of the original image could be reconstructed using the compressed image.
These compression techniques are as follows:
1. Lossless technique
2. Lossy technique

A. Lossless Compression Techniques

It uses statistics/decomposition techniques to eliminate/minimize redundancy. Hence it is also known as entropy coding. In lossless compression techniques, the original image can be perfectly recovered from the encoded image. These are also called noiseless since they do not add noise to the signal (image). Lossless compression is used only for a few applications with strongest requirements.

Following techniques are included in lossless compression:
1. Run length encoding
2. Huffman encoding
3. LZW coding
4. Area coding

B. Lossy Compression Techniques

Lossy techniques provide much higher compression ratios than lossless schemes. Lossy schemes are widely used since the quality of the reconstructed images is adequate for most applications .By this technique, the decompressed image is not identical to the original image, but reasonably close to it.

In this prediction – transformation – decomposition process is completely reversible [Wiki]. In this technique, the quantization process results in loss of information. The entropy coding after the quantization step, however it is lossless. The decoding is a reverse process. Firstly, entropy decoding is applied to compressed data to get the quantized data. Secondly, dequantization is applied to it and finally the inverse transformation to get the reconstructed image.

Major performance of lossy compression techniques depend on following factors:
1. Compression ratio
2. Signal - to - noise ratio
3. Speed of encoding & decoding.

Following techniques are included in lossy compression techniques:
1. Transformation coding
2. Vector quantization
3. Fractal coding
4. Block Truncation Coding
5. Sub band coding

III. Lossless Compression Techniques

A. Run Length Encoding

This is a very simple compression method used for sequential data. It is very useful in case of repetitive data. This technique replaces sequences of identical symbols pixels, called runs by shorter symbols. A "run" of consecutive pixels whose gray levels are identical is replaced with two values. Those are the length of the run and the gray level of all pixels in the run. RLE is mostly used in case of simple graphic images such as icons, line drawings, and animations which contains many runs. The run length code for a gray scale image is represented by a sequence { Vi , Ri } where Vi is the intensity of pixel and Ri refers to the number of consecutive pixels with the intensity Vi.
Example: (11, 11, 11, 11, 11) becomes (5, 11).

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This technique is especially suited for synthetic images containing large homogeneous regions. The encoding process is effective only if there are sequences of 4 or more repeating characters. RLE algorithms are parts of various image compression techniques like BMP, PCX, TIFF, and is also used in PDF file format, but RLE also exists as separate compression technique and file format. But most of RLE algorithms can't achieve the high compression ratios [2].

B. Huffman Encoding

This is a general technique for coding symbols based on their statistical occurrence frequencies (probabilities). The pixels in the image are treated as symbols. The symbols that occur more frequently are assigned a smaller number of bits, while the symbol that occurs less frequently reassigned a relatively larger number of bits. Huffman code is a prefix code. This means that the (binary) code of any symbol is not the prefix of the code of any other symbol. Most image coding standards use lossy techniques in the earlier stages of compression and use Huffman coding as the final step.

Apply following Steps for Huffman encoding:

1. Ranking pixel values in decreasing order of their probability.
2. Pair the two values with the lowest probabilities, labeling one of them with 0 and other with 1.
3. Link two symbols with lowest probabilities.
4. Go to step 2 until you generate a single symbol which probability is 1.
5. Trace the coding tree from a root.

C. LZW coding

LZW (Lempel- Ziv - Welch) is a dictionary based coding. Dictionary based coding can be static or dynamic. In static dictionary coding, dictionary is fixed during the encoding and decoding processes. In dynamic dictionary coding, the dictionary is updated on fly. LZW is widely used in computer industry and is implemented as compress command on UNIX. It is also use in GIF image format. A large English text file can typically be compressed via LZW to about half its original size [Wiki].

D. Area Coding

Area coding is an enhanced form of run length coding, reflecting the two dimensional character of images. This is a significant advance over the other lossless methods. For coding an image it does not make too much sense to interpret it as a sequential stream, as it is in fact an array of sequences, building up a two dimensional object. The algorithms for area coding try to find rectangular regions with the same characteristics. These regions are coded in a descriptive form as an element with two points and a certain structure. This type of coding can be highly effective but it bears the problem of a nonlinear method, which cannot be implemented in hardware. Therefore, the performance in terms of compression time is not competitive, although the compression ratio is.

IV. LOSSY COMPRESSION TECHNIQUES

A. Transformation Coding

In this coding scheme, transforms such as DFT (Discrete Fourier Transform) and DCT (Discrete Cosine Transform) are used to change the pixels in the original image into frequency domain coefficients (called transform coefficients).These coefficients have several desirable properties. One is the energy compaction property that results in most of the energy of the original data being concentrated in only a few of the significant transform coefficients. This is the basis of achieving the compression. Only those few significant coefficients are selected and the remaining is discarded. The selected coefficients are considered for further quantization and entropy encoding. DCT coding has been the most common approach to transform coding. It is also adopted in the JPEG image compression standard.

B. Vector Coding

The basic idea in this technique is to develop a dictionary of fixed-size vectors, called code vectors. A vector is usually a block of pixel values. A given image is then partitioned into non-overlapping blocks (vectors) called image vectors. Then for each vector in the dictionary code is determined and its index in the dictionary is used as the encoding of the original image vector. Thus, each image is represented by a sequence of indices that can be further entropy coded. The vector quantization algorithms are widely used for reducing the transmission bit rate or storage in case of speech and image signals. Vector quantization algorithms used to obtain better quality of the image with minimum distortion. Vector quantization (VQ) is the generalization of scalar quantization to the case of a vector [5].

C. Fractal Coding

The essential idea here is to decompose the image into segments by using standard image processing techniques such as color separation, edge detection, and spectrum and texture analysis. Then each segment is looked up in a library of fractals. The library actually contains codes called iterated function system (IFS) codes, which are compact sets of numbers. The process of matching fractals does not involve looking for exact matches, but instead looking for "best fit" matches based on the compression parameters such as encoding time, image quality, and size of output [3].

The main concept in this compression scheme is to use Iterated Function Systems (IFS) to reproduce images. Using a systematic procedure, a set of codes for a given image are determined, such that when the IFS codes are applied to a suitable set of image blocks yield an image that is a very close approximation of the original. The compression ratio for the fractal scheme is hard to measure since the image can be decoded at any scale [4]. This scheme is highly effective for compressing images that have good regularity and self-similarity.

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D. Block Truncation Coding

In this scheme, the image is divided into non overlapping blocks of pixels. For each block, one bit quantize is design separately. On the basis of these, threshold and reconstruction values are determined. The threshold is usually the mean of the pixel values in the block. Then a bitmap of the block is derived by replacing all pixels whose values are greater than or equal (less than) to the threshold by a 1 (0). Then for each segment (group of 1s and 0s) in the bitmap, the reconstruction value is determined. This is the average of the values of the corresponding pixels in the original block. The reconstructed images obtained from applying this technique have a bit rate 2 bit/pixel. This corresponds to 75% compression [6].

E. Sub Band Coding

In this scheme, the image is analysed to produce the components containing frequencies in well-defined bands, the sub bands. Subsequently, quantization and coding is applied to each of the bands. The advantage of this scheme is that the quantization and coding well suited for each of the sub bands can be designed separately. This is widely used in case of database browsing application. Sub band coding techniques are especially suitable for applications where scalability and graceful degradation are important issues [10]. Scalability means that the transmitted bit-stream can be decoded hierarchically, i.e., a low-resolution version of the transmitted image can be decoded with few operations and the full resolution image will only be decoded if necessary or desired.

V. BLOCK DIAGRAM

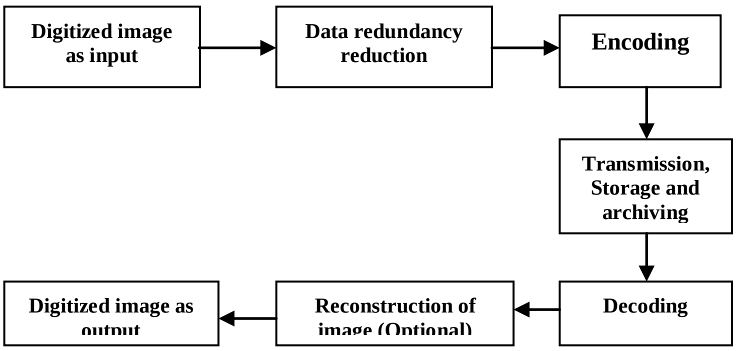

Fig.1. Block diagram for text recognition

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