IJDACR
ISSN: 2319-4863

IJDACR
International Journal Of Digital Application & Contemporary Research

International Journal of Digital Application & Contemporary Research
Website: www.ijdacr.com (Volume 5, Issue 8, March 2017)

A Review on Medical Image Compression Techniques

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Abstract –**The objective of compression is to solve the problems of transmission and archiving of digital data. These problems are related to the very large volume of digital information acquired daily in medical imaging. However, the reduction of this volume should not lead to any changes in the qualitative interpretation of the images and the value of the parameters representing the state of the organ studied. This paper reviews about the available image compression standards.**

Keywords – **JPEG, JPEG 2000, JPEG-LS, BZIP2, RAR, PPMZ, EZW, SPIHT.**

I. Introduction

In recent decades, medical imaging has undergone dramatic changes in both the development of production techniques and their use. Today, these new technologies are essential for diagnostics and their intensive use poses problems of storage and transmission.

Compressing is the process by which a certain volume of information can be represented using fewer data. These types of representations are useful because they allow to save storage and transmission resources. Data compressors are universal encoders, capable of compressing any data sequence if statistical redundancy is detected. Image compression is a similar process, but compressed data is always a digital representation of two-dimensional signals. Image compressors exploit, in addition to statistical redundancy, spatial redundancy. In this way, the levels of compression that can be achieved increase appreciably.

Computer graphics applications, especially those that generate digital photographs, can generate very large files.

Due to storage issues and the need to rapidly transmit image data over networks and the Internet, a number of image compression techniques have been developed to reduce the physical size of the files.

Most compression techniques are independent of specific file formats; In fact, many formats support several different types of compression. They form an essential part of the creation, use and storage of digital images. Most of the algorithms are specially adapted to specific circumstances, which must be understood for their actual use. For example, some are more effective at compressing monochrome (black-and-white) images, while others give better results with complex colour images. Some compression algorithms are patented and can only be used under license, others have been developed as open standards. This can be important in terms of both creation costs and long-term sustainability.

Theories of information and coding have two main objectives: The transmission of the maximum amount of information possible through a channel and the detection and correction of transmission errors due to noises in that channel. Clearly, both objectives seek to reduce costs and security in the transmission of information.

The interest in information theory, from the point of view of data compression, focuses mainly on the efficient coding of information in the absence of noise. Thus, the goal is to represent the information in the most compact way possible.

II. Compression

A compression system consists of two distinct structural blocks: an encoder and a decoder. The original image enters the encoder, which creates a series of symbols from the input data. After transmission through the channel, the coded representation enters the decoder, where a reconstruction of the coded image is generated. If the system is not error-free, a certain level of distortion will be present in the decoded image. Both the encoder and the decoder are formed by independent blocks.

Data compression is defined as the process of reducing the amount of data needed to effectively represent information, i.e., eliminating redundant data.

Types of Redundancy

In the case of image compression, three different types of redundancy are described in the literature

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(e.g. [1, 2, 3]) which can be approached in different ways:

Code Redundancy: We will refer to an image as a real function f, defined in the set $\Omega = (0,1)^2$ With $f(x, y)$ the intensity (or gray level) in the pixel (x, y). $f: \Omega \to R$. A colour image would be a vector function $f: \Omega \to R^3$ because we assume that it has three components of colour (RGB, R = red, G = green, B = blue).

Normally, in an image there is usually a set of gray levels that appear more than the rest. The determination of these levels of gray is given by the histogram of the image. If the histogram of an image is not flat, the image presents code redundancy that can be expressed using entropy. One way to eliminate coding redundancy is to assign fewer code bits to more frequent gray levels and more code bits to the less frequent gray levels. This is called variable length code.

Redundancy between Pixels: Most images have similarities or correlations between their pixels. These correlations are due to the existence of similar structures in the images, since they are not completely random. In this way, the value of a pixel can be used to predict the value of its neighbours. For example, an image with a constant gray level is completely predictable once the value of the first pixel is known. On the other hand, an image composed of white Gaussian noise is totally unpredictable.

***Psycho-Visual Redundancy*:** The human eye responds with different sensitivity to the visual information it receives. The information to which it is less sensitive can be discarded without affecting the perception of the image, so what is being eliminated is visual redundancy.

Since the elimination of psycho-visual redundancy leads to a loss of irreversible quantitative information, it is often referred to as quantification. Compression techniques such as JPEG make use of variations in quantization.

Compressive Measures

There are a large number of metrics used in measuring the efficiency of a compression system. This measurement is always relative to the data being compressed. The relative measures are always calculated by expressing a relationship between the lengths of the coding sequences before and after the compression process (A and B respectively).

We quote below some of the most commonly used measures [4]:

Bits per Symbol: A fairly intuitive metric is the number of code / symbol-source bits (BPS = Bits per symbol) obtained after compressing. This value is calculated as:

$$BPS = l \times \frac{B}{A} \qquad (1)$$

Where l is the bit size (of code) of the uncompressed representation of the source symbols.

Compression Factor: The compression factor is another measure of the level of compression achieved. Indicates the ratio between uncompressed file size A and compressed file size B and is typically expressed in the form $(X: 1)$ where:

$$X = \frac{A}{B} \qquad (2)$$

Compression Rate: To calculate the compression level, we use a measure called compression rate (CR) defined by:

$$CR = 1 - \frac{B}{A} \qquad (3)$$

III. Image Compression Techniques

Image compression techniques are based on algorithms that can be developed in both hardware and software. The performance of an image compression algorithm is based on its data compression characteristics, the distortion induced in the images and the complexity of the implementation of this algorithm. As indicated in [5]. A compression system can be modelled as a sequence of three operations:

Transformation (Mapping): It translates the set of pixels to another domain, where the quantizer and the encoder can be used effectively. It is a reversible operation.

Quantification: It performs the operation of sorting the transformed data into classes, to obtain a smaller number of values. It is an irreversible operation.

Encoding: The information already compressed is added to a binary stream containing either the information to be transmitted or the protection and identification codes of the images. It is a reversible operation.

An efficient way to achieve image compression is to encode a transform of the image, rather than the image itself. The purpose of the transformation is to obtain a set of coefficients in the transformed plane that have a lower correlation than exists in the image plane (pixel redundancy).

IV. Classification of Compression Methods

Image compression algorithms are divided into two categories:

- Lossy compression achieves its purpose by eliminating some information from the image, thus causing a loss of quality in the image.

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- Lossless compression techniques reduce the size by retaining all the original image information, and therefore there is no reduction in image quality.

Although lossy techniques can be very useful for creating versions of images for everyday use or on the Internet, they should be avoided for the archiving of master versions of images.

Lossless Compression

In several applications, such as medical image storage or business documents, error-free compressions are the only legally accepted. In satellite image processing, the high cost of data acquisition makes any transmission error or loss desirable. In digital radiography, a loss of information may make the diagnosis invalid. Therefore, the need for image compression without loss of information is desirable depending on the application of the processed image.

There is an intrinsic limitation on how much the image can be compressed, if that limit is exceeded, information necessary to recover the original image is deleted. The entropy is a measure of that limit, if it is high it means that there is a lot of random information and therefore the lossless compression ratios are very low, but in real life the images are not totally random then the entropy is low.

Error-free compression techniques are generally composed of two independent operations: design of an alternative image representation in which redundancy between pixels is reduced, and encoding of the representation to avoid encoding redundancies. These steps correspond to the symbol mapping and coding operations carried out in the coding block of the image compression model. Lossless compression techniques, as explained in [6], are classified as:

- Variable length encoding techniques.
- Bit Plane Coding Techniques.
- Coding techniques with lossless prediction.

The combination of these groups of techniques gives rise to a set of efficient methods of image compression without loss of information, used in various international standards.

Variable Length Encoding Techniques

Let's look at the most important techniques used to reduce coding redundancy:

Huffman Encoding: The most popular technique to eliminate coding redundancy is Huffman's. Developed by David Huffman in 1952 [7], it is one of the oldest and best established compression algorithms. It is a lossless algorithm and is used to provide a final stage of compression in several widely used compression systems, such as JPEG and Deflate. For a particular image, this encoding provides the least number of code symbols per source symbol. The main disadvantage is that the font symbols have to be encoded once for each image. This method works by assigning the shortest length codes to the source symbols with the highest probability of occurrence in the image. After the code has been created, the encoding and decoding are performed by the simple table query method.

The compression rate of the Huffman method varies with the type of image, but it rarely exceeds compression levels of 8: 1. This method tends to behave worse with files containing long strings of identical pixels, which are usually compressed better with other methods. Huffman is a slow and very sensitive process to the loss or addition of bits.

Arithmetic Coding: The arithmetic coding method does not generate code blocks, that is, there is no one-to-one correspondence between source symbols and code symbols, as in the case of Huffman coding and its modified versions. Instead, a single arithmetic code word is assigned to a complete string of source symbols (or message). The code word itself defines a range of real numbers between 0 and 1. As the number of symbols of the message grows, the interval used to represent it becomes smaller and the number of information units (bits) required to represent the interval becomes larger as explained in [6]. Each message symbol reduces the size of the interval according to its probability of occurrence.

The most important methods within arithmetic coding are dictionary algorithms among which the algorithms can be highlighted:

- **LZ77 (Lempel and Ziv, 1977) [8]:** The LZ77 algorithm has a very good compression rate for many types of data, but the coding speed is slow. However, decoding is very fast.
- **LZSS (Storer and Szymanski, 1982) [9]** is an improvement of the LZ77 algorithm which generally provides a higher compression ratio than this. Some of the most important software implementations in which the LZSS algorithm is included are the classic file compressors PKZIP, ARJ, LHARC, ZOO or RAR.
- **LZ78 (Lempel and Ziv 1978) [10]:** It is faster than LZ77 but with a similar compression rate.
- **LZW (Welch, 1984) [11]:** It is an improvement of the LZW algorithm. LZW compression is found in a number of common image file formats, including TIFF, GIF, and Unix compress.

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Bit Plane Coding Techniques

The above methods reduce coding redundancy. Bit plane coding techniques also address pixel redundancies in an image. They are based on decomposing a multilevel image into a series of binary images and compressing each of them by some of the existing binary compression methods.

The gray levels of a grayscale image of m bits can be represented in the form of the base polynomial 2.

$$a_{m-1}2^{m-1} + a_{m-2}2^{m-2} + \cdots + a_1 2^1 + a_0 2^0 \quad (5)$$

One of the most commonly used techniques and perhaps the simplest compression technique commonly used is RLE (Run Length Encoding). RLE algorithms work by searching for sequences of bits, bytes or pixels of the same value, and encoding the length and value of the sequence. As such, RLE achieves its best results with images containing large areas of contiguous colour, and especially monochrome images. Complex colour images, such as photographs, do not compress well because in some cases, RLE may even increase the size of the file.

There are a number of commonly used RLE variants, which are found in the TIFF, PCX and BMP image formats.

Lossy Compression

Loss coding is based on the compromise between the accuracy of the reconstructed image and the compression ratio. If, depending on the application, the resulting distortion (whether visible or not) can be tolerated, a significant increase in compression can be achieved. In fact, some lossy monochrome image compression techniques succeed in producing acceptable versions with 30: 1 compression. Lossless compression techniques, on the other hand, rarely achieve a compression ratio greater than 3: 1. As mentioned, the main difference between the two approaches is the existence or absence of the quantization block in the compression system model.

The techniques of coding digital images with loss of information are classified according to the approximation they make to the problem of reduction of psycho-visual redundancy in three groups:

- Coding techniques with Prediction
- Transformation coding techniques
- Fractal coding techniques

Coding Techniques with Prediction: Prediction coding techniques operate directly on the pixels of an image and are therefore called spatial domain methods. Prediction coding techniques include delta modulation, optimal predictors, and Lloyd-Max quantification [12]. We can find more information on each of the coding techniques in [6].

Transformation Coding Techniques: In this section, compression techniques based on the modification of an image transform are considered [14]. In transform coding techniques, a reversible transformation (Wavelets or Fourier, for example) is used to map the image to a set of transformed coefficients, which are quantized and coded. For most of the real images, most of the coefficients obtained have very small magnitudes, which can be quantified thickly or discarded directly with a small final distortion of the image. The decoder of a transform coding system performs the reverse sequence of steps to that performed by the encoder, with the exception of the quantization function.

The choice of a particular transform depends on the amount of reconstruction error permissible for a particular application and the available computational resources. Compression is performed during the quantization step, not during the transformation. The most common transformations used for the compression of digital images are Discrete Fourier Transform (DFT), Discrete Hartley Transform, Karhunen-Loeve Transform (KLT), Discrete Cosine Transform (DCT), Walsh–Hadamard Transform (WHT), Discrete Gabor Transform (DGT) and Discrete Wavelet Transform (DWT) [14].

Fractal Coding Techniques: Fractal compression uses the mathematical principles of fractal geometry to identify redundant and repeated patterns within the images [15]. These patterns can be identified by the use of geometric transformations, such as scaling and rotation, on elements of the image. Once identified, a repeated pattern needs only to be stored once, along with information about its location in the image and the transformations required in each case [16]. Fractal compression makes extremely intensive use of the computer, although the decompression is much faster. It is a losing technique that can achieve high compression rates. Unlike other lossy methods, higher compression does not produce pixelation of the image, and although information is still lost, this tends to be less obvious. Fractal compression works best with complex images and high colour depths [17, 18].

V. Image Compression Standards

There is a wide variety of image compression systems. The use of one or the other depends on the nature of the image (monochrome, grayscale, colour images, medical images, etc.) as well as the particular application (editing, rendering, storing, etc.).

IJDACR
ISSN: 2319-4863

IJDACR
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The compression standards apply different techniques together to reduce the three types of redundancy defined in section II. This section describes the most commonly used image data compression algorithms.

JPEG

The JPEG compression algorithm has its origins in attempts to develop compression techniques for the transmission of colour and grayscale images. It was developed in 1990 by the Joint Photographic Experts Group of the International Standards Organization (ISO) and CCITT (Consultative Committee for International Telephony and Telegraphy) [19]. JPEG is a lossy technique that provides very good compression rates with complex 24-bit images (true colour). It achieves its effect by eliminating image data imperceptible to the human eye, using the discrete cosine transform (DCT), followed by Huffman coding for even greater compression [20].

Figure 1: Results of the Lena image compression with the JPEG algorithm (a) Original image 512×512 with 8 bpp (b) approximate compression factor 16:1 (c) approximate compression factor 32:1 (d) approximate compression factor 64:1

The JPEG specification allows users to set the compression level, using an abstract Quality Setting. This provides a compensation between compression ratio and image quality: the higher the setting, the better the image quality, but at the expense of a larger file size.
The compression is performed in three sequential steps: DCT calculation, quantization, and Huffman variable length code assignment. The image is first subdivided into blocks of 8×8 pixels (n, m=8 in the formulas), which are processed from left to right and top to bottom. The transformation and normalization process produces a large number of null coefficients. These coefficients are arranged in zigzag form to give a 1D sequence of nonzero coefficients.

The JPEG standard is designed for the compression of digital images in colour or grayscale of real images, where compression rates higher than 25:1 can be achieved. It does not work as well on synthetic images as drawings or text.
In Figure 1 one can observe the images obtained when using the JPEG algorithm with the "Lena" image (512×512 in grayscale) with different quality settings.

JPEG 2000

JPEG 2000 replaces the JPEG algorithm, developed by the ISO JPEG group in 2000 [21]. It allows compression with and without losses, and uses the discrete wavelet transform (DWT) to achieve higher compression rates with a lower Quality of the image. The JPEG 2000 standard defines a file format (JP2). JPEG 2000 can work with higher compression levels than JPEG without resorting to major defects of the previous format with high compression rates. Generation of uniform blocks and blurry appearance. It is also better suited to the progressive loading of images. Its main disadvantages are that it tends to blur the image more than JPEG even for the same file size, and it eliminates some small details and textures that the normal JPEG format does represent. One advantage of JPEG2000 is the ability to select an "area of interest". This means that the user frames the area that he wants to visualize in more detail, with the consequent saving in the bandwidth of transmission, leaving with less details the area that does not interest [22].
Another advantage of the JPEG2000 standard is that it has a progressive resolution mode. In this mode the resolution or size of the image is increased as the information is decoded. There is also another mode called "Progressive SNR" where what is increasing is the quality of the image as it decodes more information, as explained in [23].
Initially, the images have to be transformed from the RGB colour space to another colour space, giving rise to three components that are handled separately. There are two possible options:

- ***Reversible Colour space transformation (RCT):*** It uses a modified version of the YUV colour space that does not introduce quantization errors, so it is fully reversible.
- ***Irreversible Transformation of colour Space (ICT):*** It is called "irreversible" because it has to be applied over floating-point values and causes rounding errors.

JPEG-LS

JPEG-LS (JPEG LosslesS) [24] is an image compression standard designed to achieve effective compression of lossless or near-loss images.

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The algorithm used in the JPEG-LS standard is LOCO-I (LOw COmplexity, context-based, lossless image compression algorithm) proposed by Hewlett-Packard in [25]. LOCO-I is built on a concept known as context modeling. The idea on which it is based is to use the structure of the image, modeled in terms of conditional probabilities of what is the value of the pixel that follows any other pixel of the image.

The authors of the LOCO-I algorithm realized that there was a lot of redundancy that could be exploited by taking into account the spatial context, at a very low cost compared to the use of more complex encoders such as arithmetic coding. For this reason, they decided to use Rice's coding and design a very fast compressor and decompressor. All of this has caused LOCO-I to be adopted almost unchanged for the JPEG-LS standard.

PNG

The PNG (Portable Network Graphics) format. It supports indexed colour, grayscale and high quality colour images (16 bits per pixel), plus an optional alpha channel (colour correction). This format is designed for applications such as the Internet, so the compression rate used is quite high (greater than GIF). In addition, it provides (like GIF and JPEG) a progressive display. The most notable feature of this format is its robustness to transmission errors. The lossless compression algorithm is the LZ77 arithmetic coding algorithm. Although GIF supports animation, PNG was developed as a static image format and the MNG format was created as its animated variant [26, 27].

BZIP2

Bzip2 is a lossless data compression algorithm developed by Julian Seward in 1996. It compresses more than traditional gzip or ZIP compressors, although it is slower. In most cases, bzip is outperformed by PPM algorithms in terms of compression but is twice as fast when compressing and six times faster when decompressing. Bzip2 uses the Burrows-Wheeler transform and Huffman encoding. The ancestor of bzip2 (bzip) used arithmetic coding [28].

RAR

RAR is a file format, with a lossless compression algorithm used for data compression and archiving, developed by Russian software engineer Eugene Roshal. RAR uses a compression algorithm based on the LZSS which, in turn, was based on the LZ77. This format uses what is known as solid compression, which allows you to compress several files together, so that the same search window is applied to the entire set of files, so the compression level is higher [29].

PPMZ

PPMZ is a lossless data coding algorithm developed by Charles Bloom in 1997 [30] based on PPM (Prediction by Partial Matching). PPM models use a set of previous symbols in the flow of uncompressed symbols to predict the next symbol in that flow.

The PPMZ algorithm is very efficient for compressing bitmap type images but it is not the best for encoding transformed images because it does not take into account the tree structure that is used with the EZW or EBCOT algorithms.

EZW

The EZW (Embedded Zerotree Wavelet) compression method was proposed by Shapiro in 1993 in [31]. This method exploits the properties provided by the DWT to obtain satisfactory results in compression: a large percentage of wavelength coefficients close to zero and the grouping of the energy of the image. The EZW is sensitive to the group of transmitted bits in order of meaning, which allows for an in-depth compression (embedded coding) of the image. The more bits that are added to the compression result, the more details are being transmitted.

EZW uses a binary arithmetic code and a 4-symbol alphabet to indicate the situation of the zerotrees as compactly as possible to the decoder. EZW is considered a turning point in the growing curve that relates the compression ratio to the computational cost of the algorithms. Since then, a great effort has been made to design more efficient algorithms and standardizations such as JPEG 2000 or CREW (Compression with Reversible Embedded Wavelets) from RICOH. All of them have the common denominator of using a variable length code (almost always arithmetic coding) to entropy compression using the remaining redundancy in the DWT-2D [31].

SPIHT

The SPIHT algorithm (Set Partitioning in Hierarchical Trees) was devised by Said and Pearlman in 1996 [32] and has its roots in the EZW algorithm. However SPIHT is conceptually different because it uses a fixed-length code. The length of each code word is one bit and this encoding is efficient because the probability of each symbol (which matches that of each bit or codeword) is 0.5. Its existence demonstrates that it is possible to design efficient codecs without the need to differentiate between a probabilistic model and a variable length encoder (as with the LZ compressor family).

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SPIHT is based on the classification of hierarchical trees of coefficients of the wavelet transform. Just as the EZW allows the progressive transmission of information in more significant bit order and also achieves images with high quality and high compression rates [32].

VI. Conclusion

The aim of compression is to solve the growing problems of transmission and archiving of digital data. In the field of medical imaging, these problems are linked to the ever-increasing quantity of images acquired daily by the technical improvement of acquisition systems and the development of imaging in medicine.

This paper have highlighted a state of the art of the most well-known compression techniques. It enabled us to understand the different methods and the way in which they apply the concepts presented. Predictive techniques are often the most effective in achieving the best compression rates, but they rarely offer progressive coding solutions that provide a quick summary of information. On this point, the most efficient encoders use almost all the wavelet transforms and bit map coding in order to provide a progressivity on the quality of the reconstructed image. Intra-band approaches are currently the most widely used, but inter-band encoders such as SPIHT are still up-to-date.

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