Image Compression Using K-Space Transformation Technique

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Abstract— *As a result of bandwidth and storage limitations, image compression techniques are widely used in data transmission and data storage. Image compression attempts to reduce the number of bits required to digitally represent an image while maintaining its perceived visual quality. In this paper a simplified and more effective image compression method is described. A new technique is proposed for image compression depends on a known method in the field of medical imaging, especially in the magnetic resonance imaging (MRI) known as ''K-Space" transformation, but used only in MRI image formation and was not used in image compression before. Simulation results show the effectiveness of the proposed method. The performance of this method is compared with the available jpeg compression technique over a wide number of images, showing good agreements.*

Keywords- K-Space, 2D-FFT, Image Compression.

1. Introduction

In a congested network like the Internet or low bandwidth communication for wireless transmission, image compression at a low bit rate is necessary. Image transmissions require particularly large bandwidth and storage space. Image compression technology is therefore essential to overcome these problems. The purpose of image compression is to reduce the amount of data and to achieve low bit rate digital representation without perceived loss of image quality [1].

The two fundamental principles used in image compression are redundancy and irrelevancy. Redundancy removes redundancy from the signal source and irrelevancy omits pixel values which are not noticeable by human eye. Image compression techniques reduce the number of bits required to represent an image by taking advantage of these redundancies. There are many applications requiring image compression, such as multimedia, internet, satellite imaging, remote sensing, medical imaging and preservation of art work, etc. Decades of research in this area has produced a number of image compression algorithms. Most of the effort expended over the past decades on image compression has been directed towards the application and analysis of different coding techniques to compress the image data.

In the recent years, the stringent demand of storage and transmission of images has provoked significant research interest in the field of image compression. For medical image processing, Image compression is very essential. From the famous methods in medical imaging techniques is Magnetic Resonance Imaging (MRI). MRI is a noninvasive technique routinely used to produce high-quality images of the body's internal tissues. MRI gives excellent discrimination between soft tissue types for anatomical studies and offers the potential to perform in physiological studies. Data collected during an MRI scan corresponds to samples of the two-dimensional Fourier transform of the image. The domain for this data set is commonly referred to as 'k-space' [2].

In this paper, a new technique is proposed for image compression depends on known method in the field of medical images, especially in the magnetic resonance imaging (MRI). This method depends on method of representation data in K-Space domain. Since K-Space is actually enormously simplifies the systematic exposition and comprehension of most data acquisition and evaluation methods used in MRI.

The basic idea of this method depends on transforming the image data from image domain to K-Space domain, then apply compression algorithm in K-Space domain and then transmit compressed image. Experimental results over a large number of images have shown good amount of compression of image size.

This paper is organized as follows. Related works are presented in Section 2. K-Space is illustrated in Section 3. The proposed scheme for image compression is presented in Section 4. Simulation results and discussions are given in Section 5 and finally conclusions are drawn in Section 6.

2. Related Works

Image compression may be lossy or lossless. Lossless compression is preferred for archival purposes and often for medical imaging, technical drawings, clip art, or comics. This is because lossy compression methods, especially when used at low bit rates, introduce compression artifacts. Lossy methods are especially suitable for natural images such as photographs in applications where minor (sometimes imperceptible) loss of fidelity is acceptable to achieve a substantial reduction in bit rate. The lossy compression that produces imperceptible differences may be called visually lossless.

The rapid growth of digital imaging applications, including desktop publishing, multimedia, teleconferencing and high definition television (HDTV) has increased the need for effective and standardized image compression techniques. Among the emerging standards are JPEG, for compression of still images, MPEG, for compression of motion video [3]; and CCITT H.261 for compression of video telephony and teleconferencing. All three of these standards employ a basic technique known as the discrete cosine transform (DCT) [4]. The compression standard JPEG2000 [5] accepted quite recently is based on discrete wavelet transform (DWT) and it commonly provides considerably better quality of decoded images than JPEG.

K-Space is known method in the field of medical images, especially in the magnetic resonance imaging (MRI). Most researches in K-Space concentrate in solving problems found in MR images such as motion artifacts, which corrected in k-space domain [6-8]. But K-Space used only in MRI image formation and was not used in image compression before.

3. K-Space Transformation

K-Space is the main point in MRI and understanding it is very important to know how MRI works. Data collected during an MRI scan corresponds to samples of the two-dimensional Fourier transform of the image. The domain for this data set is commonly referred to as ‘k-space’ [2]. MRI is a medical imaging technique used in radiology to visualize detailed internal structures.

The k-space is an extension of the concept of Fourier space well known in MR imaging. The k-space represents the spatial frequency information in two or three dimensions of an object. The k-space is defined by the space covered by the phase and frequency encoding data. The relationship between k-space data and image data is the Fourier transformation. The data acquisition matrix contains raw data before image processing. In 2-dimensional (2D) Fourier transform imaging, a line of data corresponds to the digitized MR signal at a particular phase encoding level. The discrete Fourier transform of a function f(x,y), which is the actual image, of size m x n can be expressed as:

$$F(u,v) = \frac{1}{mn}\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} f(x,y)\cdot e^{-2\pi i(\frac{ux}{m}+\frac{vy}{n})}$$

For u = 0, . . . ,m− 1 and for v = 0, . . . , n − 1 -------(1)

And the inverse by

$$f(x,y) = \sum_{u=0}^{m-1}\sum_{v=0}^{n-1} F(u,v)\cdot e^{2\pi i(\frac{ux}{m}+\frac{vy}{n})}$$

For x = 0, . . . ,m − 1 and for y = 0, . . . , n − 1---------(2)

The variables u and v used in equation (1) are the frequency variables, x and y are the spatial or image variables. Note that f(x,y) is the image and is real, but F(u,v) is the FT and is, in general, complex. In the literature, F(u,v) is often represented by its magnitude and phase rather than it’s real and imaginary parts, where

$$magnitude(F(u,v)) = \sqrt{R^2(u,v) + I^2(u,v)}$$ --------(3)

$$phase(F(u,v)) = \tan^{-1}[\frac{I(u,v)}{R(u,v)}]$$ --------- (4)

Basically, the magnitude tells how much of a certain frequency component is present and the phase tells where the frequency component is in the image.

A point in the raw data matrix in K-Space domain does not correspond to a point in the image matrix. Every point in the raw data matrix in K-Space domain contains part of the information for the complete image, See Fig.1a and Fig.1. The outer rows of the raw data matrix, the high spatial frequencies, provide information regarding the borders and contours of the image, the detail of the structures. The inner rows of the matrix, the low spatial frequencies, provide information on the general contrast of the image [9-11].

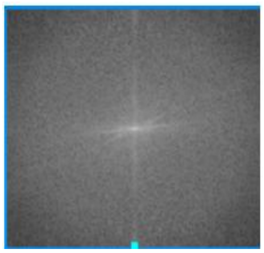

Fig.1a MRI image in K-Space domain

Fig. 1b MRI image in Image domain

4. Proposed method

The main philosophy of our image compression technique is based on concept of representation of image in k-space domain as in MR imaging. Where, In MR imaging the k-space is a temporary memory of the spatial frequency information in two or three dimensions of an image. And the Fast Fourier Transform (FFT) is used in numerical analysis to transform an image from k-space domain into image domain.

In MR imaging, most problems and MRI artifacts found in MR images such as numerous kinds of artifacts that can occur in MRI, some affect the quality of the MRI exam, noise and others may be confused with pathology, corrected in k-space domain to obtain MR images with high quality. Since K-space is a 2D plot of spatial frequencies, and so there is no positional relationship between points in k-space and points on the image. Every single point in k-space contributes to the entire image.

Since image processing in k-space domain give us more prefect solutions of image problems than processing in image domain in MRI. From this point this image compression technique on transforming images into K-Space domain and compress image, then retransform image back to image domain. Transforming image to K-Space domain is conducted by performing two inverses Fourier transforms orthogonal to each other. When an image is transformed from the spatial domain to the K-Space domain, the values of the resulting transform represent the amplitudes of particular horizontal and vertical frequencies.

This image information in the K-space domain shows how often patterns are repeated within an image. Low frequencies represent gradual variations in an image, while high frequencies correspond to abrupt variations in the image. Low frequencies tend to contain the most information because they determine the overall shape or pattern in the image, as shown in figure 2 an image formed taking only the center of the K-Space. High frequencies provide detail in the image as shown in figure 3, the peripheral regions of the K-Space encode for the edges of the image.

Note, the data type returned by the FFT is complex, which contains real and imaginary parts. The real part is the amplitude, and the imaginary part is the phase. The proposed method, is concerned with the amplitude, which is the only part represented in the surface and displays of the results of the transformation.

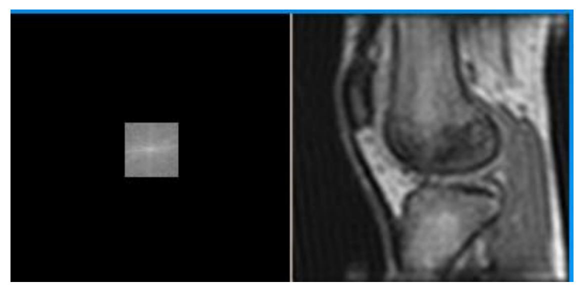

Fig.2 Image formed taking only the center of the K-Space

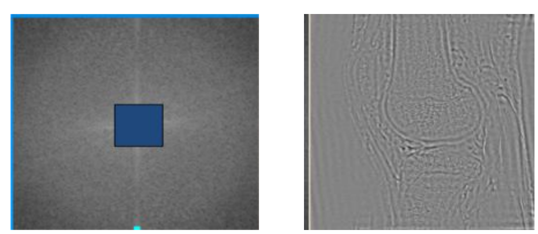

Fig.3 peripheral regions of the K-Space encode for the edges of the image.

This property of image is exploited to design a very effective image compression technique. Testing on a wide variety of images has provided satisfactory results. The technique used in this compression methodology is described in this section. The algorithms designed as per our technique are as follows:

A. COMPRESS (Source Image)

This is the main algorithm for compression. This algorithm will be used to compress source image.

1. Read the source image as input.
2. Compute two-dimensional inverse Fourier transform (2D IFFT) for this image to convert it into k-space domain.
3. Shift zero-frequency component to center of spectrum, this is useful for visualizing the Fourier transform with the zero-frequency component in the middle of the spectrum.
4. As mention above in k-space, each data point in k-space consists of the summation of MR signal from all voxels in image space. And general spatial information is concentrated towards the center of "K-Space", so we apply filter on k-space matrix image to select part center of the K-Space. For example, suppose k-space matrix dimension is 256x256, we apply filter to select only 32x32 , then take new k-space matrix (32x32) as a compressed image which transformed or stored in very small area than original image as shown in figure 4.
5. Use transmitted coding technique as Run-Length Encoding (RLE) or Huffman code to transmit compressed image. RLE is a simple technique to compress digital data by representing successive runs of the same value in the data as the value followed by the count, rather than the original run of values. The goal is to reduce the amount of data needed to be stored or transmitted. RLE yielded Addison compression ratio of almost 2:1. Other encoding techniques can be used as Huffman code which yielded Addison compression ratio of almost 1.5:1.

B. DECOMPRESS (Compressed-Image)

For decompression or decoding the compressed image:

1. Read the compressed image which is in K-Space domain.
2. Decode RLE or Huffman coding data.
3. Determine the size of the image (32x32).
4. Fill the surrounded matrix by zeros padding to convert matrix to original size 256x256. As shown in figure 5.
5. Undo the effects of Shift zero-frequency component to center of spectrum to redistribute frequency components along all k-space image.
6. Compute two dimension Fourier transform (2D FFT) for this image to convert it from k-space domain into image domain
7. Result image is stored as the decompressed Image with quality depends on the required compression ratio.

The compression ratio equations of proposed technique are:

Compression ratio before RLE (CR1) = (original image size)/ (compressed k-space image) ---------- (5)

The overall compression ratio (CR)= CR1 x compression yielded from RLE ----------------(6)

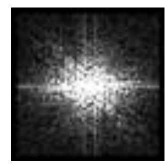

Fig.4 Image in k-space domain after compression (32x32)

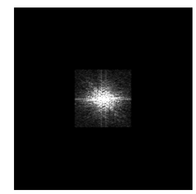

Fig.5 Image in k-space domain after zeros padding (256x256)

5. Simulation Results

All simulations were processed using MATLAB 7 environment on PC (Intel 2.0 GHz processor, 1 GB of RAM). Mean square error (MSE) measure and peak signal-to-noise ratio (PSNR) are used to determine the reconstructed image quality. MSE is using the following equation:

$$\mathrm{MSE} = \frac{1}{N \cdot M} \sum_{x=0}^{N-1} \sum_{y=0}^{M-1} \left[f'(x,y) - f(x,y) \right]^2, \quad \text{--(7)}$$

Where f(x,y) and $f'(x,y)$ represent the original and the reconstructed images, respectively; M and N represent the image size. And the peak signal-to-noise ratio (PSNR) in dB is calculated using the following equation:

$$\mathrm{PSNR} = 10 \times \log_{10} \frac{255^2}{\mathrm{MSE}} \, \mathrm{dB}, \quad \text{------(8)}$$

The size of the compressed image (SOCI) and the Compression Ratio (CR) are calculated as in equations (5) and (6).

The proposed scheme was tested by different standard test images, Lena, Pepper, cameraman, gray and color images with different sizes. Also we have tested text, medical, compressed and color images. It is obvious from PSNR results that, proposal technique works quite well for different types of images, and the images would be decompressed quite perfect. For gray image, Fig.6a shows the original Lena image with size [256x256] and Fig.6b shows the reconstructed image after decompressed the image with compression ratio equal 8 and PSNR equal 38 dB and figure 6c compression ratio equal 32 and PSNR still more than 32 dB.

Fig.6a Original Lena image

Fig.6b Compressed image (CR=8 & PSNR=38 dB

Fig.6c Compressed image (CR=32 & PSNR=32.7 dB)

Table 1 presents results of testing the new image compression procedure of standard Lena image at different compression ratios. From Table 1 it is evident that high compression ratio can be achieved in our scheme which reaches to 64 with PSNR near to 30 dB.

CR	PSNR (dB)
8	38
16	36
24	35
32	32.7
48	29.76
64	29.03
128	26.5

Table 1 Compression ratio of Lena image

For color images, Fig.7a shows the original pepper image with size [256x256x3] and Fig.7b shows the reconstructed image after decompressed the image with compression ratio equal 32 and PSNR still more than 30 dB.

Fig.7 a Original color image

Fig.7b Compressed image (CR=32)

Also, the text image as shown in figure 8 gave perfect results at high compression ratios.

Fig.8a Original Text Image

Fig.8b Compressed Image (CR=32)

Comparing the performance of the proposed scheme with the result of standard JPEG compression for Lena image in table 2 and figure 9, the compression ratio and PSNR obtained using proposed scheme is better than results of JPEG.

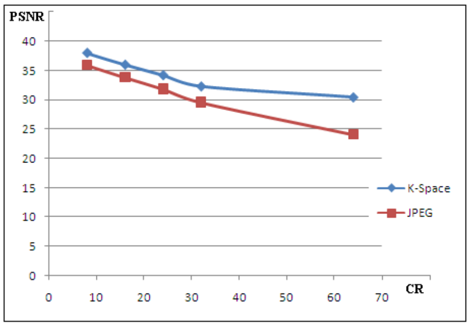

Fig.9 comparing the obtained results with JPEG For Lena image

CR	PSNR for proposed scheme	PSNR In JPEG
8	38	35.88
16	36	33.81
24	34.21	31.84
32	32.29	29.56
64	30.43	24.11

Table 2 Comparing the obtained results with JPEG For Lena image

6. Conclusion

This paper has proposed a new scheme for image compression at very low bit rate. In this paper, a new technique is proposed for image compression depends on known method in the field of medical images, especially in the Magnetic Resonance Imaging (MRI) known as ''K-Space", but used only in MRI image formation and was not used in image compression before. This scheme basically depends on concept of K-Space transformation technique.

The main aim of the proposed scheme is to achieve high compression ratio without much compromise in the image quality. We have tested our proposed scheme by many different standard test images, gray, color, text and medical images at different compression ratios, which gave perfect results at high compression ratios. We have compared the performance of our proposed scheme with some other image compression schemes, the proposed method better compression ratio than traditional methods. Moreover, we have presented results showing that the proposed algorithm produces better image quality than the standard JPEG compression algorithm.

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