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Enhancing Image Quality in Compression and Fading Channels: A Wavelet-Based Approach with Db2 and De-noising Filters

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ABSTRACT

The relentless growth in digital image data and its widespread application across various fields such as medical imaging, satellite imaging, and online content delivery necessitates efficient compression techniques to reduce storage requirements and facilitate faster transmission. However, traditional compression methods often lead to a significant degradation in image quality, particularly at high compression ratios, making the recovery of the original image fidelity challenging. This paper investigates the impact of compression ratio and PSNR on image quality, utilizing the 256×256 as a test image. It introduces a novel technique combining discrete wavelet transforms with Db2 wavelet and various de-noising filters (Wiener, Median) to enhance decompression quality measures, such as SNR and BER, over existing methods. Further exploration is conducted on the effect of increasing compression ratios on image quality in flat fading channels using QPSK and 8-PSK modulation techniques with the Db2 wavelet transform. Comparative results demonstrate the efficacy of the proposed technique in maintaining higher quality in decompressed images. This study not only underscores the trade-off between compression ratio and image quality but also showcases the potential of Db2 wavelet transforms in improving performance in fading channel conditions for different modulation schemes.

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1. INTRODUCTION

Image Compression has been the major area of research because of the increasing demand for visual communications in entertainment, medical and business application over the existing band limited channels. For image compression, it is very necessary that the selection of transform reduce the size of the resultant data as compared to the original data set [1,2]. Image processing for a wireless transmission is a challenging task because of the amount of image data that need to be processed in real time having the restriction of transmission bandwidth and other limited resources of the wireless network. One of the most important and challenging task of current and future communication is transmission of high quality image from source to destination with least error where limitation of bandwidth is a prime problem [1]. By the advent of multimedia communication, the multimedia transmission of multimedia over wireless links is considered as one of the major application of future communication systems, and such systems require the use of high storage capacity and less error transmission. Image processing includes any form of information processing in which the input is an image. Many image processing technique derive from the application of signal processing techniques to the domain of images 2-dimensional signals such as photographs or video. Most of the signals processing concepts that apply to one-dimensional signals such as resolution, dynamic range, bandwidth, filtering etc. are extend naturally to images as well [3-5]. Image compression is an important field of research that has been studied for nearly three decade. Compressed images have numerous applications in diverse areas such as high definition television, on-line product catalogs and other multimedia application. Another important application is browsing where focus is on getting high compression. For many years, the most popular image compression a technique was based on the discrete cosine transform (DCT) [6-8]. In the recent past, wavelets had emerged as an important technique for image compression. The key idea employed in image compression is that there is statistical structure present in an image. Virtually all image compression algorithms exploit this statistical structure to devise a compressed representation of an image. In recent years, many researchers have proposed compression algorithms based on the wavelet decomposition of an image. Since these wavelet-based algorithms have proved to be very successful [9].

A. Image Compression

In image compression the JPEG standard has already been widely used. It uses DCT and Huffman coding techniques. Its main disadvantage is when the coded bit rate is lower than a certain value (about 0.25 bits/pixel), there are blocking effects in the decoded image, due to the 88 block two-dimensional (2-D) DCT [10-11]. Also, if the image is directly transmitted over noisy a channel which is usually the case for wireless applications it is easy to lose blocks, because Huffman coding is a VLC. The noisier the channel, the more blocks are lost. Recently the wavelet decomposition has been proved to be a better tool for image compression. Especially for high compression ratios, it perform better than DCT based JPEG. Thus, the new JPEG 2000 standard adopt wavelet sub-band coding. Pixels that closed to each other are called the neighborhood of the representative pixel [12-15]. These related to 4-neighbhor, 8-neighbhor,and n-neighbors relationship.4-neighbors pixel are related to two horizontal pixel and two vertically upward pixel.8-neighbhor has two vertical, two horizontal,4-diagonal pixel [12].

B. Need of Image Compression

In recent years, digital images are becoming more and more important. Digital cameras are now cheap and technically mature. As a consequence, digital images are replacing conventional analog images in almost every field. Example ranges from holiday pictures to medical images, like x-ray tomography [13]. So, there is a natural need to store image on a computer and also to transmit them over the internet, to share them with other persons. The big problem is that digital images are quite memory-consuming, and so a need to compress images is also quite natural if one wants to store lots of images with a rather high resolution or wants to transmit these images via a channel with limited bandwidth [14]. Although memory is getting cheaper and cheaper these days it is still not unlimited and also the number and even more severe the resolution of images one may want to store has increased in the last years. Furthermore, we should not forget that transferring images is still an issue, as the bandwidth of networks, may they be wireless or wired, is still quite limited, actually too limited to transfer images in a raw format [13-16].

2. Daubechie Wavelet

These Daubechies wavelets are chosen to have the highest number A of vanishing moments, means this does not imply the good smoothness for given width N=2A, and on the possible solutions that one is chosen which scaling filter has external phase as shown in Fig. 1. For fast wavelet transform is easy to put into practice. These wavelets are mainly used for solving self-similarity property of a signal. Haar and Daubechies wavelet have orthogonality, & they have some nice features [17-20]:

- Wavelet function and the scaling function are same for forward and inverse transform.
- Different subspaces between the correlation in the signal are removed. The Haar wavelet transform is simplest type of wavelet, and fastest compare to other wavelet. But because of its discontinuity, it makes difficult to simulate a continuous signal, is main drawback.

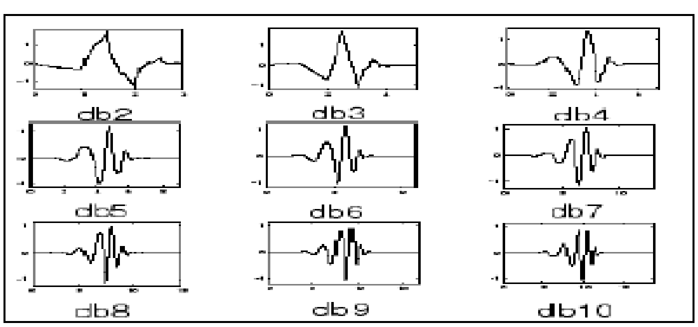

Fig. 1: Waveforms of Daubechies Wavelet

3. PROPOSED METHODOLOGY

Image de-noising is an active area of research in digital image processing. The aim of image de-noising is to restore/recover original image from corrupted one with no or minimum distortion. The impulse noise is most wide-spread and important noise in digital images. It affects image at the real time of acquisition due to noisy sensor at the time of transmission due to channel errors (noise) or faulty memory locations in hardware by synchronization errors in the image digitizing or transmission. The data that affected by salt-and-pepper noise change drastically, because their amplitudes (amp.) are either relatively high or relatively low. If pixel values not reflect the true intensities of the real scene, so it causes the degradation of the image quality. Various linear & non-linear filtering scheme has been proposed for the removal of impulse noise. But linear filter lack usability due to blurring of high-frequency (f_h) components, and sharp details in the image. To overcome the shortcoming of linear filters and non-linear filters have been adopted, and are still widely used for their useful properties like edge preservation & robustness against impulse noise [17-18].

A. Quadrature Phase Shift Keying (QPSK)

This is also known as four-level PSK where each element represents more than one bit. Each symbol contains two bits and it uses the phase shift of π/2, means 90º instead of shifting the phase 180º. In this mechanism, the constellation consists of four points but the decision is always made in two bits. This mechanism can ensure the efficient use of bandwidth and higher spectral efficiency. The principle equation (1) of QPSK Modulation of the technique is [15]:

$$S(t) = \begin{cases} A\cos(2\pi f_c t), \text{ for binary } 1 \\ A\cos(2\pi f_c t + \pi), \text{ for binary } 0 \\ A\cos(2\pi f_c t), \text{ for binary } 1 \\ -A\cos(2\pi f_c t), \text{ for binary } 0 \end{cases} \qquad (1)$$

B. Fading Channels

Rayleigh and Rician fading channels are useful models of real-world phenomena in wireless communications. These phenomena include multipath scattering effects, time dispersion, and Doppler shifts that arise from relative motion between the transmitter and receiver.

The shaded shapes represent reflectors such as buildings. The major paths result in the arrival of delayed versions of the signal at the receiver. In addition, the radio signal undergoes scattering on a local scale for each major path. Such local scattering is typically characterized by a large number of Reflections by objects near the mobile system. These irresolvable components combine at the receiver Rx.) & give rise to the phenomenon known as multipath fading (e.g. MIMO). *Each* major path behaves as a discrete fading path [12-14].

C. Rayleigh Fading Channel

The information is transmitted in an environment with obstacles (Non Line-of-sight NLOS) as shown in Fig. 2, more than one transmission paths will appear as result of the reflection(s). The receiver will then have to process a signal which is a superposition of several different transmission paths. If there exists a large number of transmission paths may be modeled as statistically independent; the central limit theorem will give the channel the statistical characteristics of a Rayleigh Distribution [9].

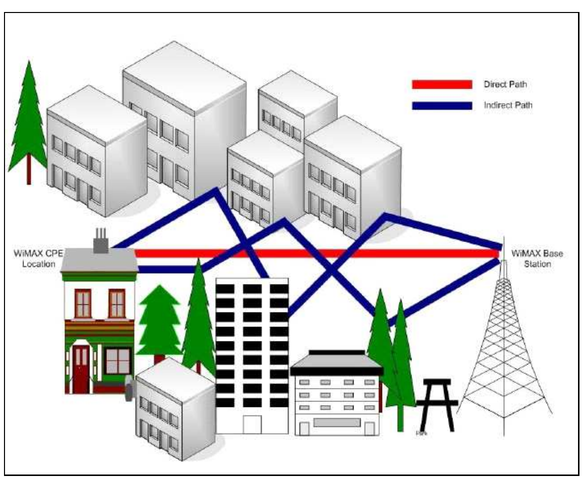

Fig. 2: Non Line-of-sight prorogation

NLOS (indoor, city) Rayleigh fading occurs when there is no multipath LOS between transmitter and receiver and have only indirect path which is called NLOS to receive the resultant waves. The Rayleigh Fading is one kind of model which propagates the environment of radio signal. Rayleigh fading works as a reasonable model when many objects in environment which scatter radio signal before arriving of receiver. When there is no propagation dominant during line of sight between transmitter and receiver on that time Rayleigh Fading is most applicable. On the other hand Rician Fading is more applicable then Rayleigh Fading when there is dominant line of sight. During our simulation we used Rayleigh Fading when we simulate the performance of Bit Error Rate (BER) verses Signal to Noise Ratio (SNR).

D. Rayleigh Fading Distribution

In mobile radio channels, the Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal, or the envelope of an individual multipath component. It is well known that the envelope of the sum of two Quadrature Gaussian noise signals obeys a Rayleigh distribution. The Rayleigh distribution has a probability density function (pdf) [18] given by:

$$P(r) = \begin{cases} \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right), (0 \le r \le \infty) \\ 0, (r < 0) \end{cases} \quad (2)$$

E. Compression Ratio (CR)

Compression ratio (CR) represents how much data is compressed using the compression algorithm with respect to the original image size. So, this metric is an important measurement in image compressor's performance evaluation. Increase of CR is good for storage application since it reduces the transmission time consumption by the image but at the same time it reduce the reconstructed image quality, so it is required between the compression ratio and image quality metrics. In literature, several methods exist to measure the CR. For finding Compression Ratio, we used number of bit to represent the size of original image and the number of bit to represent the size compressed image. So, Compression ratio shows how much times image has been compressed.

By the ratio of the size of original data set to the size of the compressed data set we can find out compression ratio.

$$\text{Comprassion ratio} = \frac{X}{Y} \times 100 \quad (3)$$

Where X = Number of Bytes in the original data set, Y = Number of Bytes in the Compressed data set . It is clearer by this example. Example: An image, 1024 pixel×1024 pixel×24 bit, without compression would require 3MB of storage. If after compression storage requirement is reduced to 300 KB, so by using formula we find the compression ratio as 10:1.

4. Bit-Error-Rate (BER)

When number of bits error occurs within one second in a transmitted signal then we called it as Bit Error Rate (BER). In another sentence Bit Error rate is one type of parameter which used to access the system that can transmit digital signal from one end to other end. We can define BER as follows:

$$BER = \frac{\text{Error Nimber}}{\text{Total Number of bit sent}} \quad (4)$$

If transmitter and receiver's medium are good in a particular time and Signal-to-Noise Ratio is high, then Bit Error rate is low. In our thesis simulation we generated random signal when noise occurs after that we got the value of Bit error rate.

5. Mean square error (MSE)

MSE is called squared error loss. These error measures the average of the square of the "error. It is incorporates both the variance of the estimator and its bias so it is second moment of the error (about the origin). Mean square error is minimizes the sum of squared errors due to bias and due to variance, so is criterion for an estimator. By the average of the square of the difference between the desired response and the actual system output, MSE is calculated. As a loss function, MSE is called squared error loss. For calculation, both the variance of the estimator and its bias mentioned in equation 5.When estimator is unbiased, the MSE is the variance. Taking the square root of MSE yields the root mean squared error or RMSE, by standard deviation which has the same units as the quantity being estimated. For standard error, the RMSE is the square root of the variance, when estimator is unbiased.

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i,j) - K(i,j)]^2 \quad (5)$$

Where m and n is image size and I (i,j) is the input image and K (i,j) is retrieved image.

6. SNR (Signal-to-Noise Ratio)

Energy per bit to noise power spectral density ratio is important especially in simulation. Whenever we are simulating and comparing the Bit Error rate (BER) the performance of adaptive modulation technique is very necessary. The normalized form of is Signal-to-Noise Ratio (SNR). In tele-communication, Signal-to-Noise ratio is the form of power ratio between a signal and background noise [20-21].

$$SNR = \frac{P_{Signal}}{P_{Noise}} \quad (7)$$

Here P is mean power. In this case the signal and the background noise are measuredwith the same point of view if the measurement will take across the same impedance then SNR would be obtained by measuring the square of the amplitude ratio.

$$SNR = \frac{P_{Signal}}{P_{Noise}} = \left(\frac{A_{Signal}}{A_{Noise}}\right)^2 \quad (8)$$

In another word Signal to Noise Ratio**:** In many applications the Mean Square Error is

expressed in terms of a Signal to Noise Ratio (SNR) which defined in decibels (dB) as

$$SNR = 10 log \frac{\sigma^2}{\sigma_e^2} \quad (9)$$

Where is the variance of the desired image andis average variance.

7. Peak signal-to-noise ratio (PSNR)

The peak signal-to-noise ratio often abbreviated PSNR, is an term used for the ratio between the maximum possible power of a signal and power of corrupting noise that affects the fidelity of its representation. So by the ratio of signal variance and reconstruction error variance, PSNR can be defined[14].It is also explained as the ratio between the maximum possible power of signal and the power of corrupting noise. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of logarithmic decibel scale. So it is most used as a measure of quality of reproduction of image compression etc. PSNR is easily defined which for two monochrome images I and K where one of the images is considered noisy.

Encoding Time, Decoding Time and Transforming Time: Any compression system uses one of the encoding techniques to encode the input information. The encoding operation is very crucial for the success of compression system. It involves the representation of the input information in a form suitable for storage and transmission. The time required to perform this operation is referred as encoding time. The reverse process to encoding is decoding and the corresponding time required to decode an encoded data is decoding time. In general, the information to be compressed will be represented in spatial domain. To compress the data, it was observed that it is convenient to represent the data in frequency domain. Hence the information in time domain needs to be converted into frequency domain. For that, one of the transforming techniques will be used. Again it involves some time. This time is referred to as transforming time. These times are measured in seconds (s).

8. Simulation Result

The simulation result presented in the thesis focuses mainly on Compression ratio and PSNR which typically affects the picture quality. Most of the times as researchers goes on increasing the compression ratio quality of the resulting image use to go down for the proposed technique, test image “Cameraman.tif” size 256 *256. The Results are shown in a quality measures such as SNR and BER for decompressed “Cameraman.tif” image are calculated and compared. Table 1 shows the comparison of the results with the proposed technique of discrete wavelet techniques Db2 wavelet with De-noising filter, Wiener filter and Median filter to the existing network respectively.

9. Fading Channel on QPSK and 8-PSK Modulation with Db2 Transform

In this performance we consider flat fading channel on different modulation techniques with Db2 wavelet transform. Most of the times as researchers go on increasing the compression ratio the quality of the resulting image use to go down for the proposed technique, test image “Cameraman.tif” size 256 $\times$ 256.In the Fig. 3 (a) show the (a) Original image, Compressed image and De-compressed image. The performance of Db2 Wavelet transformer on QPSK modulation and 8-PSK modulation with Fading Channel as shown in Fig. 4 and Fig. 5 respectively.

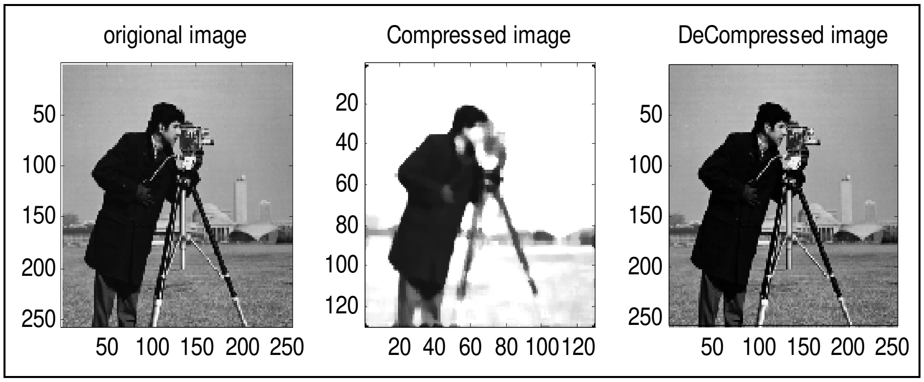

Fig. 3 (a) Original image, Compressed image and De-compressed image

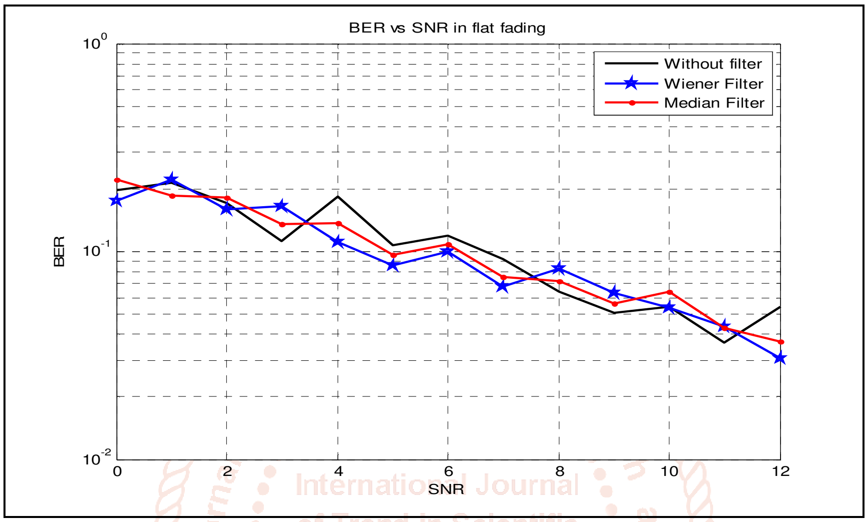

Fig 4: Performance of Db2 Wavelet Transformer on QPSK Modulation with Fading Channel

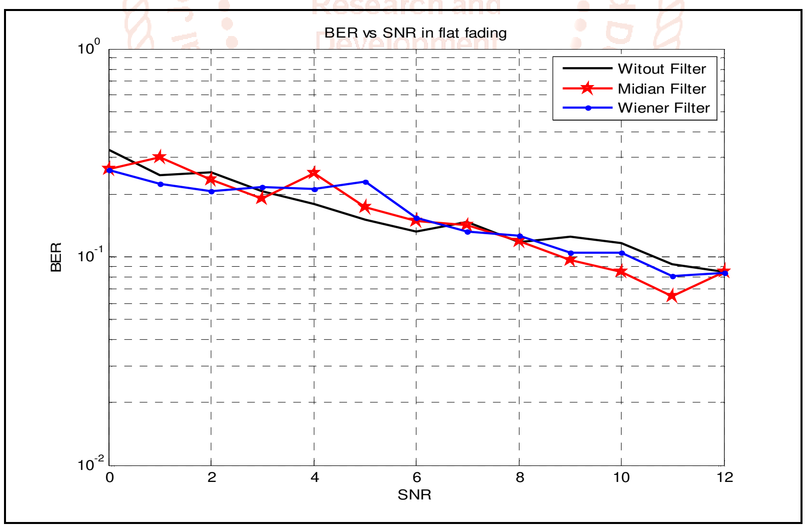

Fig 5: Performance of Db2 Wavelet Transformer on 8-PSK Modulation with Fading Channel

Table 1 Showing CR values on various stages

Wavelet	Modulation	Channel	CR		
			Without filter	Wiener filter	Median filter
Db2	QPSK	Flat fading	7.3192	6.1780	8.4726
Db2	8-PSK	Flat fading	7.0192	6.0195	8.3036

Table 2 PSNR values on various stages

Channel model	PSK modulation	Wavelet technique	PSNR		
			Without filter	Wiener filter	Median filter
Flat fading	QPSK	Db2	15.2458	15.6548	16.1604
Flat fading	8-PSK	Db2	14.7627	14.8627	15.3723

Conclusion: This scenario underscores the critical need for innovative compression techniques that not only achieve high compression ratios but also preserve image quality, especially in challenging transmission environments. This approach aims to provide a balanced solution that optimizes both compression efficiency and image quality restoration capabilities, even in the presence of channel imperfections such as fading, thereby fulfilling the pressing demands of modern digital imaging applications. The performance output plotted between BER verses SNR for QPSK and 8-PSK modulation techniques with Channel (AWGN and Flat fading) using Wiener filter and Median filter. From the simulation results, we find that that if we increase SNR value, BER performance is improved. We had also noticed that if using Db2 wavelet compression 8.3726, increasing compression ratio for transmitting image.

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