A Novel Hybrid Image Compression Algorithm for Medical Images

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Abstract

SMART e-Health Gateway or E-health administrations have been endeavoring to utilize the multimedia computing and multimedia communication such as teleradiology, teleconsultation, telemedicine, telediagnosis and telematics for better patient care and timely services. With the expanding utilization of multimedia technologies and utility computing such as cloud computing, grid computing and cluster computing on the medical domain make the e-Health offerings extremely effective, reasonable and inevitable benefits even to the common men. Due to the advent of therapeutic picture and medical image modalities such as X-ray, CT imaging, MRI, ultrasound and digital video, a large volume of 2D and 3D image data are being created in hospitals and medical organizations nowadays. The photo-realistic 2D and 3D models are not only for representation and visualization but also for smart movement and transport of substance for the Image Guided Surgery (IGS). One of the challenges, obstacles and hurdles faced by the health care institutions is limited data transmission speed to get to, exchange and share these therapeutic pictures for the smart E-health services for the vital and essential indicative analysis.

Image compression techniques have been incorporated in order to reduce the bandwidth requirement and economically transfer of medical images for primary diagnosis. Efficient image compression solutions are becoming more critical with the recent growth of data intensive, multimedia-based web applications. In this paper a novel hybrid image compression algorithm is proposed which overcome all limitations discussed above and enhance the quality of medical images using different filters.

Keywords: - Image Compression, Wavelet Filters, Digital Images and Communication in medicine Partitioning in hierarchical trees.

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Introduction

SMART e-Health Gateway or E-health administrations have been endeavouring to utilize the multimedia computing and multimedia communication such as teleradiology, teleconsultation, telemedicine, telediagnosis and telematics for better patient care and timely services [1]. With the expanding utilization of multimedia technologies and utility computing such as cloud computing, grid computing and cluster computing on the medical domain make the e-Health offerings extremely effective, reasonable and inevitable benefits even to the common men [2]-[4].

Biomedical imaging system has become one of the most imperative representation, visualization and interpretation methods and procedures in the field of medicine not only for diagnostic of diseases and abnormalities but it also plays a major role in modern e-health services [3],[5],[6]. The medical communication system is an innovative and cutting edge technology that allows any type of medical information and therapeutic data to be transmitted within the framework from point of care to the desired specialist(s). The information is transmitted safely, securely and quickly for conveyance to smart phones or PCs with the goal that doctor's can review the data and provide opinions and assessments [7],[8]. Nowadays a tremendous volume of therapeutic pictures and medical images are produced in both 2D and 3D through various advancement remedial imaging modalities, particularly, Magnetic Resonance Imaging (MRI), Ultrasound Imaging (US), Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET), Nuclear Medicine (Scintigraphy), Computed Tomography (CT) pictures, Digital Subtraction Angiography (DSA), Digital Flurography (DF) and X-ray imaging (Radiography) [2]-[4]. Wearable Internet of Things (IoT) devices, Ubiquitous Sensor Networks (USN) and Body Sensor Networks (BSN) furthermore create an immense collection of biosignals, for instance, heart-rate, oxygen level, breath and blood pressure at low cost [4].

Storing and transmitting such a large volume of medical image data and bio-signals for e-health services on utility computing like cloud platform across the globe for telediagnosis is very critical, tedious and time consuming job [9],[10,[11]. For the past two decades, capable and effective compression algorithms have been proposed and utilized in order to diminish transmission time and storage costs. It is most likely that image compression is one of the successful, inevitable and predominant research areas in the field of image processing and that transform based image compression is very efficient and practically adopted in JPEG and JPEG-2000 coder [12],[13]-[14]. A well known transform based data compression techniques are Discrete Cosine Transform (DCT) Karhunen-Loeve Transform (KLT) [8],[11], Discrete Fourier Transform (DFT) [8],[15], Discrete Sine Transform (DST) [8],[19], Walsh Hadamard Transform (WHT) [8],[14], Burrow-Wheeler (BWT) [8] and Discrete Wavelet Transform (DWT) [8],[5],[11]. The wavelet transform has emerged as cutting edge technology not only in the field of image processing but also in the domain of image compression. Recently variety of medical image compression methods using wavelet transforms have been proposed by many researchers [16]-[20].

The good quality of the picture is essential not only for a proper and reliable teleconsultation but also for the visual information about the patient’s physical condition [16]. It is well known that objective image quality measures play important roles in a variety of image and video processing applications and also ascertain and characterize the digital image processing systems such as compression, communication, printing, analysis, registration, restoration, enhancement and watermarking [17]. The quality assessment of medical image compression is a crucial and essential process in order to provide the cost effective services to the common men in the healthcare sector [18]-[19]. In this study, we evaluate the performance of state-of-the-art quality metrics with respect to compressed medical images from different modalities [20],[21. We investigate not only the performance of the emerging image compression standard but also high effectiveness coding for medical image compression. The simulation results show that diagnostically reliable compressed image can be obtained through the advanced and propelled wavelet based algorithms [22]

In spite of rapid progress in mass-storage density, processor speed and digital communication system performance, the demand for data storage and data-transmission bandwidth continues to surpass the capabilities of available technologies [23]. Hence, there have been expanding endeavours to develop reliable compression techniques that provide cost-effective solutions for the storage and transmission of visual information for therapeutic and medical applications [2].

One of the challenges and real issues for the health care institutions and hospitals is storing and transferring a large volume of medical images through limited bandwidth network configurations on the utility computing [25]–[30]. Image compression techniques have increased the viability not only by reducing the bandwidth requirement but also cost effective delivery of medical images for primary diagnosis [31]. Hence, image compression plays a vital role both for saving the memory space and for transferring such a large volume of data across the globe through compressed format. As a matter of fact that medical image compression is one of the active research fields all over the world not only for the computer scientists and medical professionals but also for the common men for cost effective delivery of the patient's care [32].

They are different procedures and techniques utilized for image compression in both lossy and lossless [80]. In spite of the fact that lossy compression gives high compression ratio, the quality of reconstructed image is poor and that cannot be used for medical applications due to adverse effects of diagnosis and legal cases. Researchers all over the world are still working towards to achieve high compression ratio with better quality of images for telemedicine. The aim and goal of the compression algorithm is to maximize the compression ratio and minimize the mean square error of the image [33].

Considering these points and other concerns, the data compression and the tools required in this field represent the backbone of these applications [34]. Be that as it may, the image compression is not a straightforward task as it has its own arduousness and restrictions. Among these challenges and difficulties is the computation complexity, processing time, power consumption and storage area. This proposal follows up on the past issues to provide efficient hybrid algorithmic approach for the data transforms used in image and video compression systems, particularly when these issues become crucial in the case of multidimensional signals, for example, medical images and video streams for the cloud platform [35],[36].

Wavelets are one of the powerful tools and de facto standard for studying time-frequency behaviour of finite-energy signals. It also provides a coherent set of concepts, methods, and algorithms that are adapted to a variety of non-stationary signals which are well suited for numerical signal processing [37],[3],[39.

The advantages of the wavelet decomposition over Fourier transforms present themselves when transforming a signal that has time varying and/or singularity characteristics [40],[41]. Multiresolution and wavelet theory has recently found applications in a remarkable range of disciplines, for example, data compression, digital signal processing (speech and image processing), image analysis, statistics, and modeling of nonlinear dynamic processes. Wavelet transforms are known to have excellent energy compaction characteristics and are able to provide perfect reconstruction and immaculate recreation. Therefore, they are ideal for signal/image processing. The shifting (or translation) and scaling (or dilation) are unique to wavelets. Orthogonality of wavelets with respect to dilations leads to multi-grid representation [10],[17],[19].

The primary component of DWT is multiscale representation of function. By using the wavelets, given function can be analyzed at various levels of resolution. The DWT is additionally invertible and can be orthogonal [42]. JPEG-2000 is a recently developed compression standard for still images that depends on Discrete Wavelet Transform (DWT) technique [43]. Wavelet transform has emerged as very powerful tool for data compression [44]. Wavelets appear to be a suitable tool for this task, because they allow analysis of images at various levels of resolution. Motivation to this research work was seeking new strategies for quantitative examination of lossless image compression for medical images on cloud platform [45]

Like any other framework, metrics of performance of a data compression are important criteria for selection of the algorithm. The performance measures of data compression algorithms can be looked at from different perspectives depending on the application requirements: amount of compression achieved, objective and subjective quality of the reconstructed data, relative complexity of the algorithm, speed of execution, etc. The principal trouble in testing an image compression system is the way to choose which test pictures and images to use for the assessment. The image substance being seen impacts the view of value independent of specialized parameters of the framework [43]-[45]. The compression performance for images with high spectral activity is fairly insensitive to choice of compression method. The best way for choosing wavelet functions is to select optimal basis for images with moderate spectral activity. This wavelet will give satisfying results for other types of medical images [40]. The purpose of performance analysis of this research is to analyze a set of wavelet functions (wavelets) for a medical image compression system and to highlight the benefits of this transform relating to today's technique uniquely on the cloud platform [38]. Image quality is measured objectively using peak signal to noise ratio or picture quality scale and subjectively using perceived image quality. The impacts of various wavelet functions, filter orders, number of decompositions, image contents and compression ratios are inspected and examined. The outcome of the research provides a good reference for application developers to choose a good wavelet compression system for their application [42].

There are two specific applications of interests in this research, namely, cloud computing and medical imaging. As mentioned earlier, medical imaging are becoming popular but transmitting such a large amount of bits using a normal communications link can be slow and might be exorbitant utilizing mobile devices or smart phones. Current cloud computing have several constraints that is, limited storage capacity, and relatively limited communication speed.

The other application region of enthusiasm for this exploration is compression of medical images which will be the possible solution to the small screen factor is a scalable compression system. This is possible with a wavelet based compression system that can decompose the image to any desired level (in theory) and hence offer a trade off between the image quality (PSNR) and image size (bytes transmitted).

The usage of mobile devices like Personal Digital Assistants (PDA) is becoming more widespread among doctors who need to access data such as medical images from remote areas.. As mentioned earlier, the bandwidth and storage constraints of mobile devices means that medical images too must be compressed before transmission and storage. The trade off between bit rate and image quality is much more important when medical applications are being considered. Under a few circumstances, speed and consequently low bpp may be the important factor whereas in others, image quality will be paramount.

- The proposed algorithm can be utilized for real time applications, for example, videoconferencing, tele-medicine and tele-consultation where fast transmission is required between the patients and the remotely found specialist.
- The proposed algorithm can also be a good option for the image storage and retrieval on the cloud based biomedical imaging framework effectively, economically and efficiently.
- The main advantage of the image compression is not only to minimize the memory space for storing the big data that are generated but also to transmit a vast amount of data through limited channels as quickly as possible that saves the time, energy and cost.

- As the medical images are in compressed form while in transmission, information uprightness, secrecy and legitimacy can be guaranteed that the customer information will not be assaulted by the system gate crashers and network intruders.
- Expanded comprehension of the cloud computing for digital image processing in general and multimedia computing and communication for medical image compression in particular.

1. Literature Review

Poon et al. (2015), observes that increasing demand for radiological services over the past few years and there has been a growing trend toward introducing medical imaging across hospitals worldwide. Medical imaging technologies consist of a number of components including PACS (Picture Archiving Communication Systems), RIS (Radiology Information Systems) and HIS (Hospital Information Systems) which are typically linked and interfaced through a computer network. He concluded that the implementation of technological components of medical imaging particularly digital imaging modalities and PACS/RIS is very expensive [31].
Ravichandran et al. (2015) argue that healthcare researchers are moving towards their efforts to the cloud platform in order to process, store, exchange and use a large amount of medical image data which are generated and acquired through various advance medical modalities [30]-[34]. One of the challenges that arises in hospitals and medical organizations is the difficulty of transmitting such a large volume of medical images with relatively limited bandwidth. Image compression techniques have been incorporated in order to reduce the bandwidth requirement and economically transfer of medical images for primary diagnosis [14]-[18].
Rahmani et al. (2015) propose and implement an e-health services for telediagnosis on the cloud platform [19]. Biomedical images and biosignals play a major role in modern e-health services and have become an integral part of medical data communication systems. The medical communication system is a technology that allows any type of medical data to be transmitted from the point of care to the desired specialist(s). The data is transmitted securely and rapidly for delivery to mobile devices or computers so that physician's can review the data and provide opinions.
Kagadis et al. (2013) observe that cloud computing has been introduced only recently but is already one of the major topics of discussion in research and clinical settings. They conclude that healthcare researchers are moving their efforts to the cloud, because they need adequate resources to process, store, exchange, and use large quantities of medical data. Among the potential driving forces for the increased use of cloud computing in medical imaging are raw data management and image processing and sharing demands, all of which require high-capacity data storage and computing.
Different types of image compression standards such as JPEG, JPEG-2000, JPIP, and JPEG-LS have been used for the DICOM system. JPIP (JPEG 2000 Interactive Protocol) is a contemporary standard which is used for growing need to access medical images fast while enabling interoperability in clinical and radiological system. *Bostanci et al.* (2014) use a spatial statistics of image features for performance comparison and they conducted an experiment based on colour and edge properties of the images.
Saha et al. (2000) comprehends on how image statistics can impact lossy coding performance. *Sheikh et al.* (2006) study in depth on image information and visual quality and argued that image quality depends on the coder and the background of the images. *Field* (1987) suggests that a knowledge of the statistical features can lead to a better understanding of why the visual system codes do and also stressed that one must understand the nature of the environment before one can understand the nature of visual processing.

Several methods have been suggested in the literature trying to overcome the drawbacks of subjective measures. The well known and classic work of quality assessment for image systems are summarized here. Wang et al. (2004) suggest that how Image quality assessment can be measured from error visibility to structural similarity. Wang and A. C. Bovik (2004) elucidate in their research report that why image quality assessment is so difficult specially on multimedia domain [28]. These indicators provide quality results in concordance with human judgment which requires the integration of the major properties of the Human Visual System (HVS).

From the literature survey, it is evident that lossless image compression, the encoding time and algorithm complexity is too high. To overcome these difficulties, an efficient hybrid algorithmic approach for medical image compression method based on Discrete Wavelet transform (DWT) and a suitable variable entropy encoding is proposed. Secondly, the trait features of the existing algorithms are carefully investigated and found that the trade off between compression ratio and the picture quality is also investigated or evaluated based on different wavelet filters, number of decompositions, image contents and statistical analysis of the medical images. Thirdly, research work is also investigated, examined and found out the various state of the art image quality metrics for gray scale and their application to medical image compression system.

For the past two decades, efficient compression algorithms have been proposed and used in order to reduce transmission time and storage costs. The quality evaluation of medical image compression is an essential process in order to provide the cost effective services to the common men in the health care sector. In the above literature study, we have observed that the image quality measurement is still an unsolved problem today. New studies exploiting certain aspects of the HVS report reasonable success in quantifying certain types of distortion based on subjective ranking. This issue is continuing to expand and has achieved a certain maturity level within the community of multimedia communication and multimedia computing.

2. Proposed Method

Motivation to this research work was to identify the most appropriate wavelet filter based on quantitative analysis of lossless image compression for medical images on cloud platform. From the above simulation results, different wavelet filter produces different PSNR. The PSNR values vary from 50.2 db to 56.11 db for each category of images. This large variation in PSNR could be attributed to the characteristics of the image. Furthermore, some wavelet filters perform better than others depending on the image being compressed. For example, 'bior4.4' wavelet performs better than the 'haar' wavelet. This result is consistent with the findings that biorthogonal wavelets provide the best performance in image compression based on compression ratio and PSNR values.

Novelty of our simulation results can be useful for selecting the right or appropriate wavelet filter for the developers of image processing software. It is comprehended that the results can also be extended in facilitating the selection of the right wavelet for other images like aerial images, synthetic images, scanned images and compound images. We comprehend that wavelet filter biorthogonal and filter order gives the better performance. The cause and effect of this investigation is not only based on the PSNR values but also MSE and CR values. Apart from these parameters, we have investigated the image quality analysis based on other indices and discussed in upcoming slides.

In this proposed hypothesis, we have implemented a hybrid algorithm for medical image compression based on Daubechies wavelet, global thresholding and Huffman encoding. In our experiment, we have investigated the trade-off between quality of the reconstructed image and number of decomposition levels of the wavelet filter. The performance of the image coder is evaluated based on the PSNR obtained. In earlier research work [34] concluded that the coding efficiency is contributed by the first five levels of decomposition of the wavelet filter.

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Justification for conducting experiment of the proposed hypothesis "The quality of compressed image depends on the number of decompositions" , is given below:
In theory, a wavelet based compression techniques can decompose the image to any desired level but in practice it is not feasible due to high computational time. Motivation of this research work is to investigate the trade-off between the number of levels of image decomposition and quality of the reconstructed image.

Our study results also proved its consistency that quality of the coder is not significantly changed from the third level to the fifth level of wavelet decomposition. Based on the above investigation, we comprehend that it would be reasonable to use the first three levels of decomposition for better performance of image compression on medical images for time limited computational complexity (practically proved with experimental set ups).

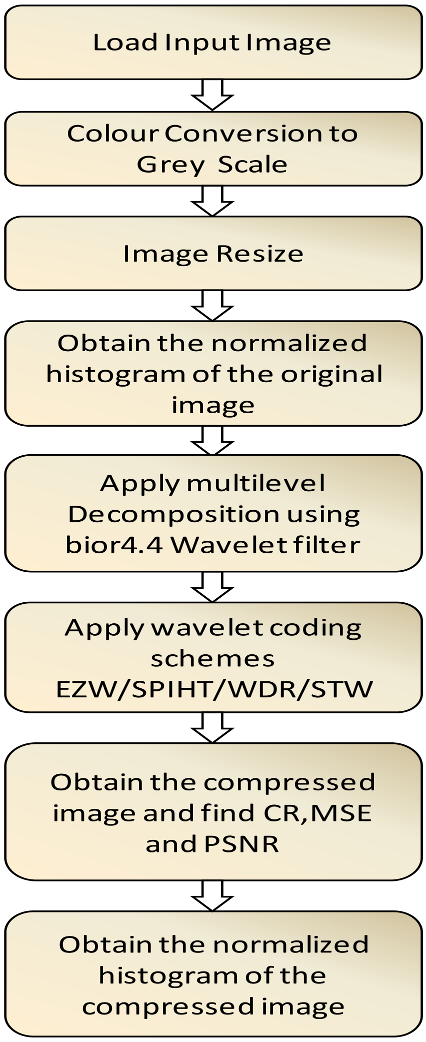


Fig 1.1 Flow Diagram of the proposed method for evaluation of state-of-the-art coder

1. Load medical image in MATLAB using Image Acquisition system.
2. Pre-processing of colour images
3. Study pre-processing effects of the given image and draw histogram of the original image.
4. Apply Forward Discrete Wavelet Transform (2D-DWT) using bior4.4 mother wavelet
5. Apply 3-level wavelet decomposition
6. Apply any one of the wavelet image compression coders (EZW / SPIHT / STW/ WDR)

7. Perform wavelet reconstruction
8. Study histogram probability reduction function on RGB components using Mean intensities (energy, entropy, and image gradients).
9. Study quality assessment of the compressed image based on CR, MSE and PSNR
10. Repeat the above all steps for rest of the images.

We have proposed a simple statistical model in Fig 1.8 that consists of the following steps:

3. Implementation Results and Discussions

In this proposed research work, we have implemented a hybrid algorithm for medical image compression system based on high-efficiency coding scheme, namely, Embedded Zero Tree (EZW), Set Partitioning in Hierarchical Trees (SPIHT), Spatial Orientation Tree (STW) and Wavelet Difference Reduction (WDR) techniques on medical images

In our experiment, we have investigated the trade-off between quality of the reconstructed image and type of coder. The performance of the image coder is evaluated based on the Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Compression Ratio (CR) and Bit per Pixel (BPP) for a selected set of medical images of different modalities. The results show that diagnostically reliable compressed image can be obtained through the advanced wavelet-based algorithms. Our results provide insight into the design issues of optimizing wavelet coders, as well as a good reference for application developers to choose from an increasingly large family of wavelet coders for their applications. The research methodology of the proposed work and algorithmic for identifying the best state of the art compression coder based on the wavelet techniques are summarized as follows.

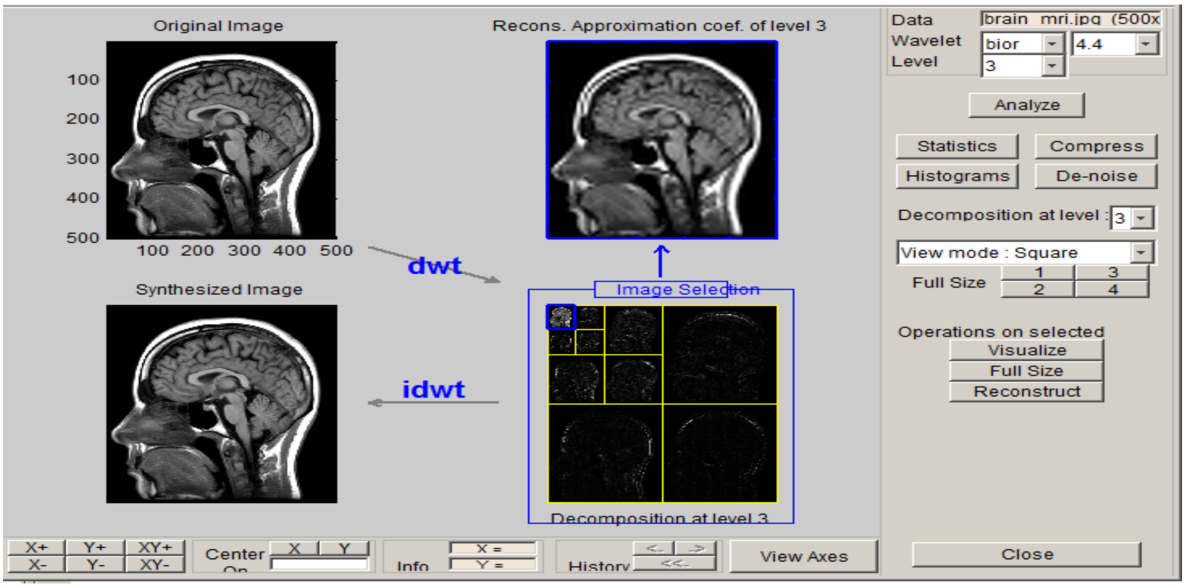


Fig 1.2 Simulation output of the experimental results

In this experiment, we have done compression and reconstruction of a selected set of medical images from different modalities by using the Daubechies (db2) wavelet filter at four different decomposition levels which are level 1, level 2, level 3, and level 5 [6]. All these images are grey scale image with depth 8 bits per pixel. The following figures show comparison of reconstructed X-ray image (256 x256 pixels, 8 bit pixel) for 1,2,3,5 levels of decompositions at bit rate 1 bpp.

Table 1.1 - Performance of EZW coder

LOOP	BPP	CR	MSE	PSNR
8	0.7891	9.8633	208.813	24.933
9	1.342	16.7725	87.275	28.722
10	2.223	27.7832	34.071	32.807
11	3.559	44.4824	10.802	37.796
12	5.279	65.9912	3.647	42.512

Table 1.2 - Performance of SPIHT coder

LOOP	BPP	CR	MSE	PSNR
8	0.5156	6.4453	257.604	24.021
9	0.8379	10.4736	106.77	27.846
10	1.385	17.3096	43.772	31.719
11	2.227	27.832	15.331	36.275
12	3.248	40.6006	5.277	40.907

Table 1.3 - Performance of STW coder

LOOP	BPP	CR	MSE	PSNR
8	0.7207	9.0088	205.501	25.003
9	1.195	14.9414	84.777	28.848
10	2.072	25.9033	31.511	33.146
11	3.439	42.9932	8.451	38.862
12	5.109	63.8672	1.59	46.118

Table 1.4 - Performance of WDR coder

LOOP	BPP	CR	MSE	PSNR
8	0.7969	9.9609	208.813	24.933
9	1.326	16.5771	87.275	28.722
10	2.283	28.54	34.071	32.807
11	3.836	47.9492	10.802	37.796

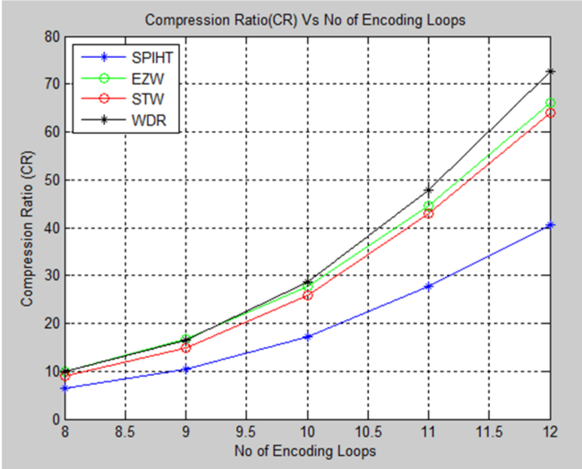


Fig 1.3 Performance of the coder based on Compression Ratio (CR) of SPIHT, EZW, STW and WDR Algorithms

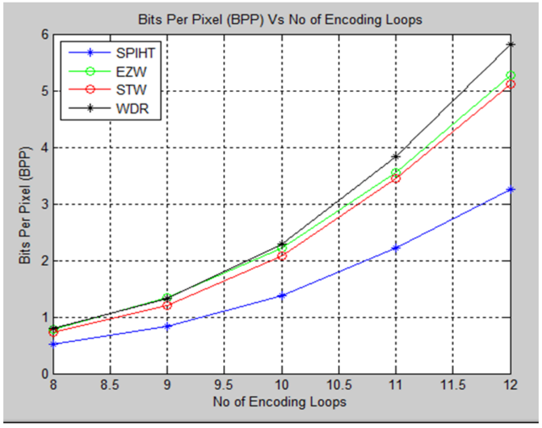


Fig 1.4 Performance of the coders based on Bits Per Pixel (BPP) of SPIHT, EZW, STW and WDR Algorithms

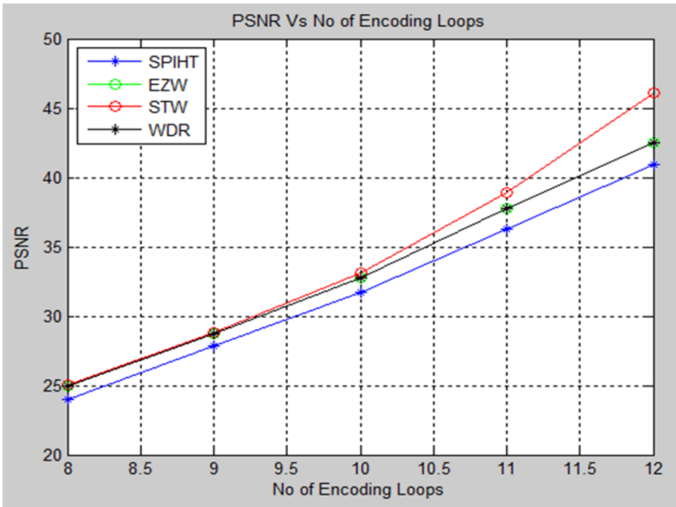


Fig 1.5 Performance of the coders based on Peak Signal to Noise Ratio (PSNR) of SPIHT, EZW, STW and WDR Algorithms

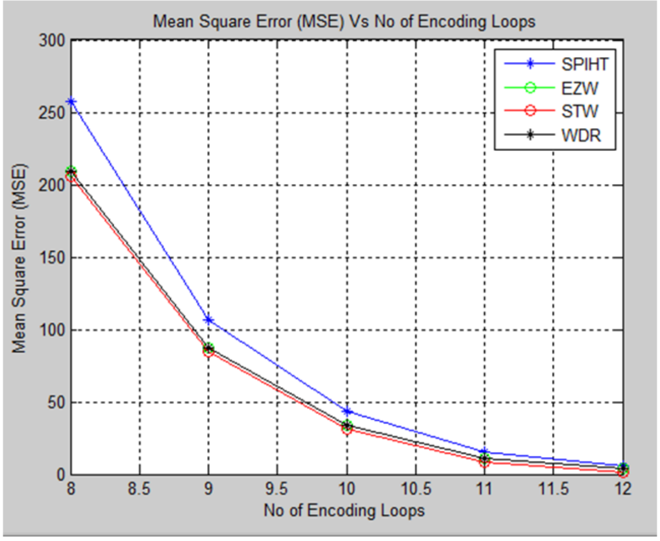


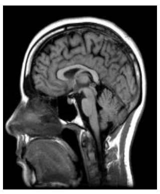
Fig 1.6 Performance of the coders based on Mean Square Error (MSE) of SPIHT, EZW, STW and WDR Algorithms

We have discussed a variety of methods, techniques and algorithms that have been proposed in the last decade and pointed out their inherent similarities and dissimilarities. We have pointed out some of the measures that are used to evaluate compression performance and showed that the state-of-the-art has improved over the years.

We have presented results from a comparative study of different wavelet-based image compression systems. The effects of different wavelet functions, filter orders, number of decompositions, image contents, and compression ratios are examined. The final choice of optimal wavelet in image compression application depends on image quality and computational complexity. We found that wavelet-based image compression prefers smooth functions of relatively short length. A suitable number of decompositions should be determined by means of image quality and less computational operation. Our results show that the choice of optimal wavelet depends on the method, which is used for picture quality evaluation. We used objective and subjective picture quality measures. The objective measures such as PSNR and MSE do not correlate well with subjective quality measures.

Image Analysis

Medical images, overall, appear to be rather complex. They are filled with objects and shadows and various surfaces containing various patterns at a wide range of orientations. Amid this complexity, it may seem surprising that such images share any consistent statistical features. Consider the six images shown in Fig. 1.7. Such images may seem widely different, but as a group they can be easily distinguished from a variety of other classes of image.


Brain MR


Chest_xray


Hand Xray


Kidney_C


Knee_mri

Liver_US

Fig. 1.7 Bench mark test medical images for evaluating Statistical Measurement

Conclusion and Future Scope

The reliance and dependence on image content is accounted for in the form of patch complexity and variability, as well as the photometric redundancies for the instance of therapeutic pictures and medical images. The discussions pointed out that although significant improvements have been made in media storage technology and transmission media, the problem of low air bandwidth that can affect the Internet access on cloud computing platform remains concern.

The most of relations of theories of wavelet transform and of system identification were portrayed in a general way, therefore they can be basically applied in various fields of image processing domain, for example, image fusion, content based image retrieval, steganography, computer vision and object identification and so on. The after effects of the exploration work portrayed in this postulation are affirmed the legitimacy of the speculations that:

1. State of the art lossless compression techniques based on DWT perform significantly superior to anything more established lossless image compression techniques based on the DCT.

2. New international standards based on DWT, for example, JPEG-2000 and JPEG-LS for compression schemes perform as well as the best state of the art lossless compression techniques.

3. Predictive schemes with statistical modelling and transform based coding perform substantially better than dictionary-based coders.

Taking everything into account, this postulation has shown that a hybrid algorithmic approach to deal with image compression can offer noteworthy change and significant improvement in therapeutic and medical image compression. Consequently, this postulation contends that justifies putting efforts and endeavours into research in image compression for therapeutic and medical applications on distributed computing and cloud computing.

- Substantial gaps to compression limits still exist
- Pattern toward algorithms to handle large, substantial, and multi-dimensional images
- Trend to multiple core processors to spur development of new parallel processing paradigms
- Open question whether quantum information theory and quantum computation will save the day.

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