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Image Compression Schemes Incorporating Modified Contrast Sensitivities of Human Visual System

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Abstract: This paper deals with the importance of working on image compression, which is reduce the number of bits needed to represent an image while maintaining a desirable quality. This is done by eliminating data that are visually unnecessary and taking advantage of redundancy that is inherent in most images.

Image compression plays a critical role in telemetric applications. Image compression involves reducing the typically massive amount of data to represent an image. This is done by eliminating data that are visually unnecessary and taking advantage of redundancy that is inherent in most images. It is desired that either single image or sequences of images be transmitted over computer networks at large distances so as that they could be used for a multitude of purposes. Image compression is essential for applications such as transmission and storage in databases. It aims to reduce the bit rate for transmission or storage while maintaining an acceptable fidelity or a good image quality.

Keywords: PSNR, DWT, HVS, CSF, JPEG2000, PIXEL, bpp, wavelet, masking.

مخططات ضغط الصور التي تتضمن حساسيات التباين المعدلة للنظام البصري البشري

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شركة نفط البصرة || العراق

المستخلص: تتناول هذه الورقة أهمية العمل على ضغط الصورة وذلك بتقليل عدد البتات اللازمة لتمثيل صورة مع الحفاظ على الجودة المرغوبة. يتم ذلك عن طريق التخلص من البيانات غير الضرورية بصريًا والاستفادة من التكرار المتأصل. في معظم الصور .يلعب ضغط الصور دورًا مهمًا في تطبيقات القياس عن بُعد. يتضمن ضغط الصورة تقليل الكمية الهائلة عادةً من البيانات لتمثيل الصورة. يتم ذلك عن طريق التخلص من البيانات غير الضرورية بصريًا والاستفادة من التكرار المتأصل في معظم الصور بأن يتم إرسال صورة واحدة أو تسلسل من الصور عبر شبكات الكمبيوتر على مسافات كبيرة بحيث يمكن استخدامها للعديد من الأغراض. يعد ضغط الصور ضروريًا للتطبيقات مثل النقل والتخزين في قواعد البيانات. يهدف إلى تقليل معدل البت للإرسال أو التخزين مع الحفاظ على دقة مقبولة أو جودة صورة جيدة.

الكلمات المفتاحية: ذروة الإشارة إلى نسبة الضوضاءPSNR ، التحويل المويجي المنفصلDWT ، نظام الرؤيا البشري HVS، دالة حساسية التباينCSF ، طريقة الضغط القياسيةJPEG2000 ، البكسل، بت لكل بكسلbpp ، مويجة، القناع.

Introduction.

Recent research in transform— based image compression has focused on the wavelet transform due to its superior performance over other transforms. This performance is often measured solely in terms of peak signal— to— noise ratio (***PSNR***). Wavelet Transform is one of the most powerful tools in digital signal processing. he field experienced a fast and impressive start. Even as the commercial rewards promised to be significant, the ideas were shared, the trials were pooled together, and the community shared the successes. Many applications use the wavelet decomposition taken as a whole. The wavelets are able to determine if a quick signal exists, and if so, can localize it. There are attempts to enhance mammograms to discriminate tumors from calcifications

Wavelet theory provides a promising hope for image processing applications because of its flexibility in representing images and its ability in take into account Human Visual System (HVS)characteristics. It is mainly used to de-correlate the image data, so the resulting wavelet coefficients can be efficiently coded. It also has good energy compaction capability that results in a high compression ratio.The Discrete Wavelet Transform (DWT) is a special case of the WT that provides a compact representation of a signal in time and frequency that can be computed efficiently. This very practical filtering algorithm yields a fast wavelet transform- a box into which a signal passes, and out of which wavelet coefficients quickly emerge. The goal of using the two-dimensional DWT with image compression is to achieve higher compression ratio in images more effectively by exploiting image structure characteristics, which are usually unemployed in image compression.

In addition, a new correlation quality criterion is suggested in this paper between PSNR quality with HVS quality. HVS quality is applied with five observers, if the compressed image is good or not according to the comparison with other images compressed at the same bit rate but with different cases (such as different image space models, filters, symmetric and asymmetric, JPEG compression method or the proposed).

The proposed HVS model prove that it improves both PSNR and HVS quality performance. For gray scale image, HVS scheme improves the PSNR quality and correlation quality methods. For color images, opponent space will improve the measure performance more than the YCbCr space. It is also shown that the proposed HVS scheme is better than last version of the international image compression standard-JPEG2000 in both PSNR quality and correlation quality measures.

Problem in this paper:

It is the amount of distortion or noise in the images required to send or save after the process of reducing the number of pixels by compressing them.

Hypothesis of this paper:

The study in this paper is in the following issues:

i. Investigating the filter performance; the proposed system in this paper applies two filter types. The first one is (biorthogonal filter) Bio 6/8 filter, while the other is (Cohen— Daubechies— Fauvaue filter 9/7) CDF 9/7 filter. Study of the effect and improvement are presented.

ii. Applying some classical and the proposed contrast sensitivity masks of contrast sensitivity function (CSF) to the wavelet coefficients according to a model of human sensitivity in spatial frequency domain.
iii. Studying the effect of symmetric and asymmetric color compression by applying the CSF masking on all components or on luminance component only. The results are also discussed.
iv. Using different color space models for color compression scheme. This research would take grayscale image model and two color image models :(Luminance-chrominance blue-chrominance red in color image space YCbCr)and opponent models. A comparative study is shown.
v. Comparing the wavelet image compression, which is used by this paper with the standard compression method-(Joint Photographic Expert Group JPEG2000) [9][11].

Aim of this paper:

It is to implement different compression techniques on real image data with different color space models. New wavelet models of the human visual system (HVS) is developed. Also, different filters with wavelet-based image compression are used to perform the quantitative measures. Studying the effect of symmetric and asymmetric color image compression is performed by applying the CSF masking in all components or in luminance component only. Finally, the wavelet image compression, which is proposed by this thesis is compared with the standard compression method—JPEG 2000.

Importance of this paper:

This paper presents a new correlation quality criteria suggested between PSNR qualities with HVS quality.

Scope of this paper:

This paper deals, in the first stage, with an explanation of image compression using wavelets, illustrating the methods of compression either for Discretion or transformation, While the second stage deals with an explanation of the human vision system HVS and its relationship to the function of sensitivities, as well as an explanation of the traditional CSF methods and the developed CSF masking method. As for the last stage, the most important experimental results of the proposed methods Compare it to the classical methods. Finally, the most important conclusions reached during the research

1- Image Compression Using Wavelets:

The goal of image compression is to reduce the number of bits needed to represent an image while maintaining a desirable quality**.** The methodologies can be divided into two types—lossless and lossy compressions, [12], [4], and [5]. Lossy compression, the original cannot be reconstructed perfectly from the compressed version. However, the best lossless schemes do not achieve competitive compression ratios compared to their lossy counterparts. For this reason, perfect reconstruction is often sacrificed for the superior compression performance provided by a lossy compression scheme [13], [1] and [11].

There are two methods that reduce some representation of image function [13]: compression by discretization (sampling), and compression by transformation. The most using of compression by sampling method is called Pulse Code Modulation(PCM). To explain the quantization process, let us have an image pixel values of 8-bit information containing 256 possible gray-scale levels in Fig (1). To reduce its level to 5-bit (32 gray-scale levels), the gray-scale levels in the range of (0-7) are mapped to " 0 " level (new level) and the gray-scale levels in the range (8-15) are mapped to " 8 " level (new level) and so on [6]. There are many other methods for quantization by sampling ; for example, uniform quantization which is mapping of a large set of possible input levels into a small sets of possible output; non uniform quantization which is used to quantize a random variable with smaller error [**10**]. Some special codes, like Huffman and Run length coding are also used for compression by discretization.

Fig (1) 1-level, wavelet decomposition of LENA' s image

Compression by transformation of model involves analyzing the image using filters, transforms....and so on [13], [6] and [2]. With the goal of finding a better representation of data or image for the purposes of encoding, many classical transform can be used for analysis of image. Fourier transform, discrete cosine transform(DCT), and wavelet transform are used in this type of compression

[11][10][7]. JPEG compression uses DCT to implemented it. Also, the wavelet transform (WT) is most useful transform which is used with compression with transformation. The proposed image compression and JPEG2000 schemes use WT in their implementations.

The most successful image compression algorithms are transform-based. Figure (2) shows a block diagram of the transform image compression system [13]. In first stage, the image is transformed into a domain where the image information is represented in a more compact form. The transform block moves image data to a domain that is more appropriate for compression than the spatial domain. Transform coding is representing the signal to be compressed in an alternate domain. By design, this transform should have two properties for the class of signals to be compressed. First, it must have the ability to translate the image to small coefficients. Second, the transform must have the result of coefficients, which is related to the original image. The most commonly used transforms today are the DCT, the wavelet transform, and (The generalized lapped orthogonal transform GenLOT). It should be noted that wavelet transforms allow some additional freedom in the selection of the particular wavelet filter used; in contrast, there is only one DCT.Wavelet-based transforms perform slightly better than GenLOT at medium bit rate, but it is a difficult select one over the other at high or low bit rates[13].

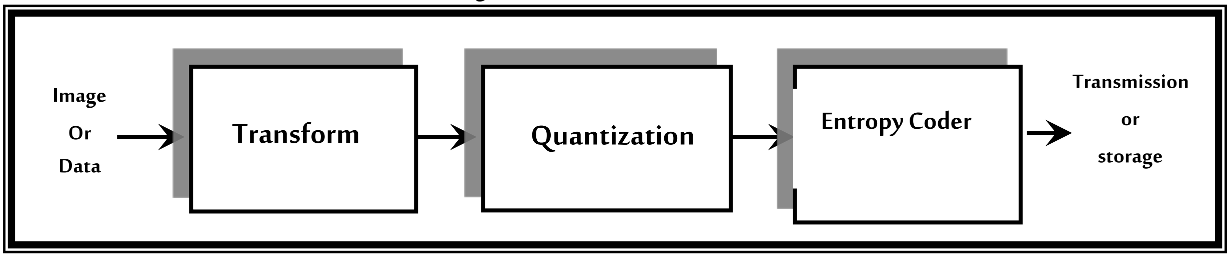

Fig (2) Block diagram of the transform image compression system

In the second stage of Fig. 2, the transform coefficients are quantized. This lossy stage, in which some useless information is irretrievably thrown away, results in a compressed image. In this paper, (the Set Partitioning In Hierarchical Trees SPIHT) quantization is employed. The final step is coding. Typically, an entropy coder used to remove redundancy in the bit stream. The arithmetic, Huffman, and run-length coding schemes are the most popular entropy coders. Entropy coding substitutes a sequence of codes for a sequence of symbols, where the codes are chosen to have fewer bits when the probability of occurrence of the corresponding symbol is higher [13][7]. In this paper, entropy coding is not use to interest, since we are interested in the utilization of wavelet transform in image compression and its benefits for the compression process.

2- The human visual system HVS & The contrast sensitivity function CSF:

The human visual system (HVS) consists of two functional parts, the eye and the vision part of the brain. The brain does all of the complex image processing, while the eye functions as the biological equivalent of a camera. Light reaches our eye and hits the photoreceptors on the retina, and they send the signal through nerves to the brain, where an image is formed. HVS research offers mathematical models of how humans see the world. For example, models have been developed to characterize humans' sensitivity to brightness and color[8].

The contrast sensitivity function (CSF) describes humans' sensitivity to spatial frequencies. The CSF is the most widely used perceptual attribute for both simple and complex image quality metrics. Its name refers to the method of weighting of the wavelet coefficients relative with perceptual descriptors [13]. The contrast sensitivity value is a function of the spatial frequency, which can be determined experimentally [12], [2] [11] and[8]. The contrast sensitivity function is first proposed by Manos and Sakrison [13], and described by the following frequency response:

$$H(f) = 2.6(0.0192 + 0.114 f)e^{[-(0.114f)^{1.1}} \quad .....(1)$$

where spatial frequency is $f = (f_x^{\,2} + f_y^{\,2})^{0.5}$ with units of cycles/degree. f_x and f_y are the horizontal and vertical spatial frequencies.

The spatial frequency can be normalized by with the following relation [13]:

$$f(\text{cycles/degree}) = f_n(\text{cycles/pixel}) \cdot f_s(\text{pixels/degree}) \quad .....(2)$$

where f_n is the normalized spatial frequency with units of cycles/pixel. Since our observers are sitting at an approximate viewing distance of 2 feet, f_s is set to 64 pixels/degree. This value for f_s is equivalent to a viewing distance of four times the image height (the image height is approximately 6 inches). In (3.2), since f has a range between 0 and $f_s/2$, f_n has a range between 0 and 0.5.

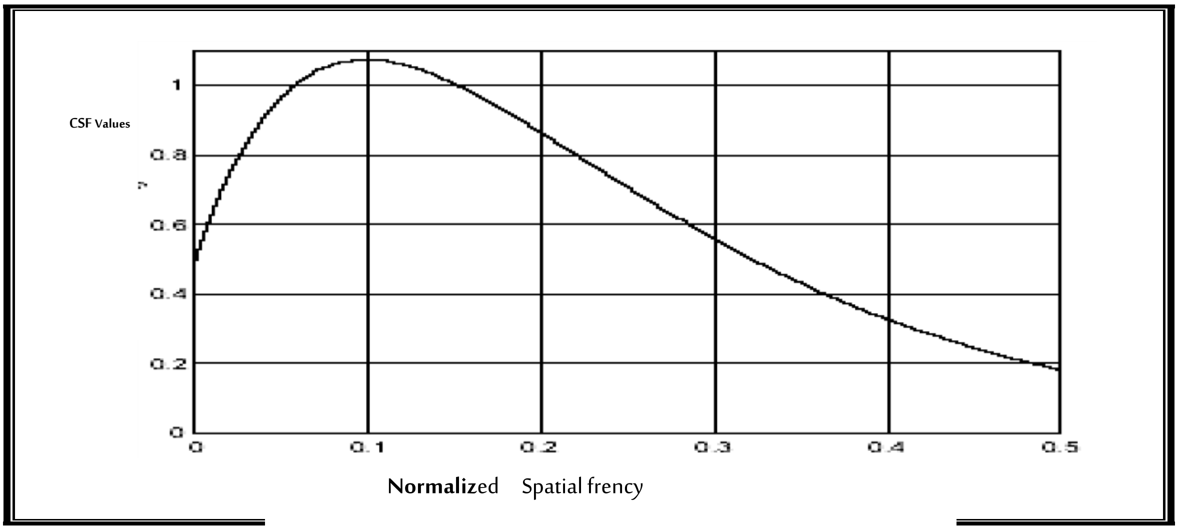

Fig (3) CSF Mask

The curve of luminance CSF verses normalized frequency is shown in Fig. 3. CSF curves exist for chrominance stimuli as well. However, unlike luminance stimuli, humans' sensitivity to chrominance stimuli is relatively uniform across spatial frequency .One application of HVS models to image compression has been the use of perceptual weighting schemes—including CSF masks—to weight the transform coefficients before quantization. Figure 4 shows how the CSF mask is applied and subsequently inverted in the compression system(for color images, there are three of these systems in parallel one for each color space). The inverse CSF mask is then generated by simply inverting the weighting factors.

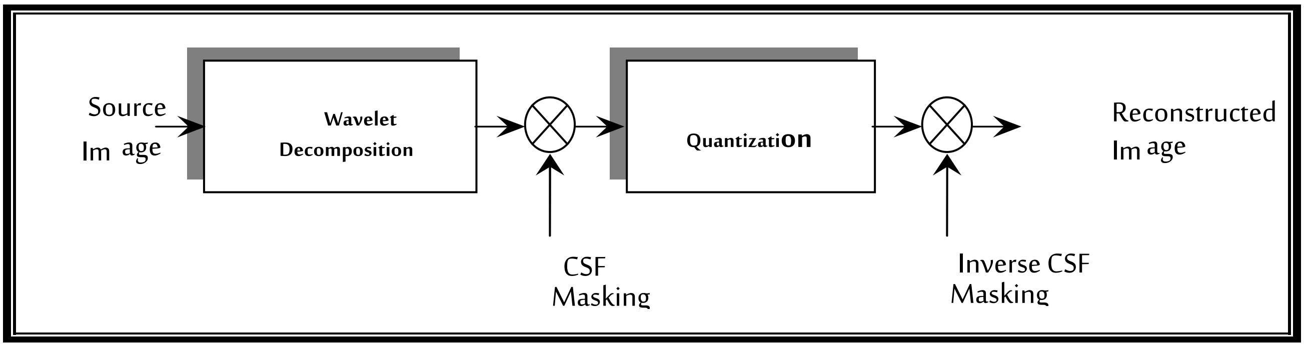

Fig (4) Block diagram of CSF and inverse CSF masking

2.1. Classical CSF Masking Methods

The first step in creating a (Discrete Wavelet Transform) DWT CSF mask is to perform a wavelet decomposition of the CSF curve. Next, we determine the mask weights from this decomposition is determined. These weights were determined in using two different methods and led to two DWT CSF masks: the 6-weight DWT CSF mask and the 11-weight DWT CSF mask[**13**].

A band-average CSF mask gets its weights directly from the CSF curve in the normalized spatial frequency domain—not in the wavelet domain like the DWT CSF masks. While, the peak CSF mask also derives its weights directly from the CSF curve in the normalized spatial frequency domain [13].

2.2 The improved 11-Weight DWT CSF Mask:

The weights in this method are determined using the following modified steps:

1- Take the DWT of the CSF curve in Figure 3. Figure 6 shows the wavelet decomposition of the CSF curve with all of the **V** subspaces; the **W** subspaces remain the same as shown in Figure 5.
2- Label the peak of the $\mathbf{W_5}$ subspace as $\mathbf{p_5}$, the peak of the $\mathbf{W_4}$ subspace as $\mathbf{p_4}$, and so on. Label the peak of the V_5 subspace as $\mathbf{q_5}$, the peak of the subspace as $\mathbf{q_4}$, and so on.
3- In the first level of the decomposition, the weight for the HH subband is given by $\mathbf{p_5}$. The weights for the LH and HL subbands are given by $\sqrt{(q_5 + p_5) \times 2}$.
4- In the second level of the decomposition, the weight for HHLL subband is given by $\mathbf{p_4}$. The weights for the LHLL and HLLL subbands are given by $\sqrt{(q_4 + p_4) \times 2}$

5- In each subsequent level of the decomposition, continue to weight the band pass subbands in this manner.

6- At the final level, the weight for the lowest frequency subband(LL LL LL LL LL)is given by **q_1**.This method yields 11unique weights in th mask.

7- Finally, all of the peaks are normalized so that the lowest peak is equal to one. The final 11-weight DWT CSF mask is shown in Fig. 7 with the weights shown for each subband.

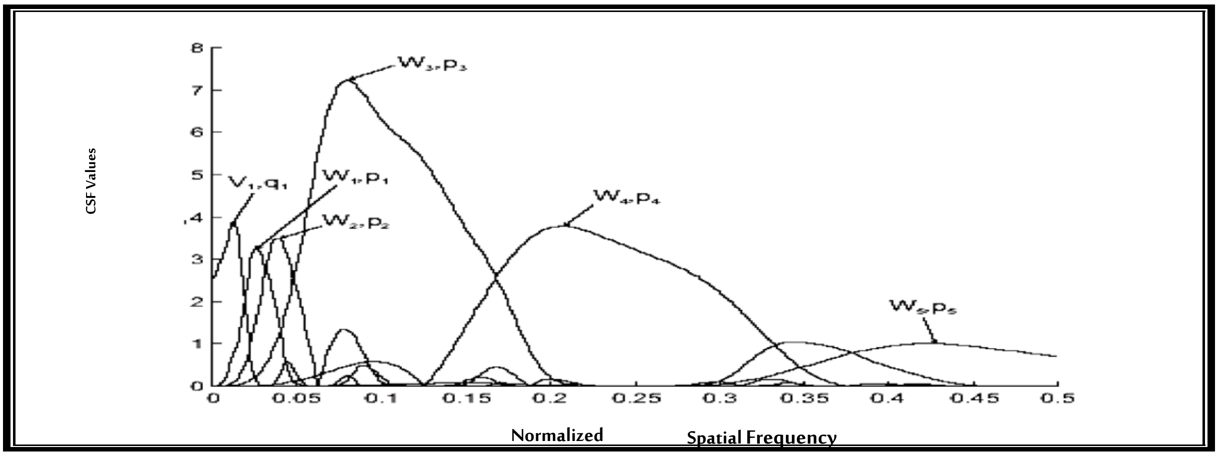

Fig (5) 5-level wavelet decomposition of CSF for 6-weight mask

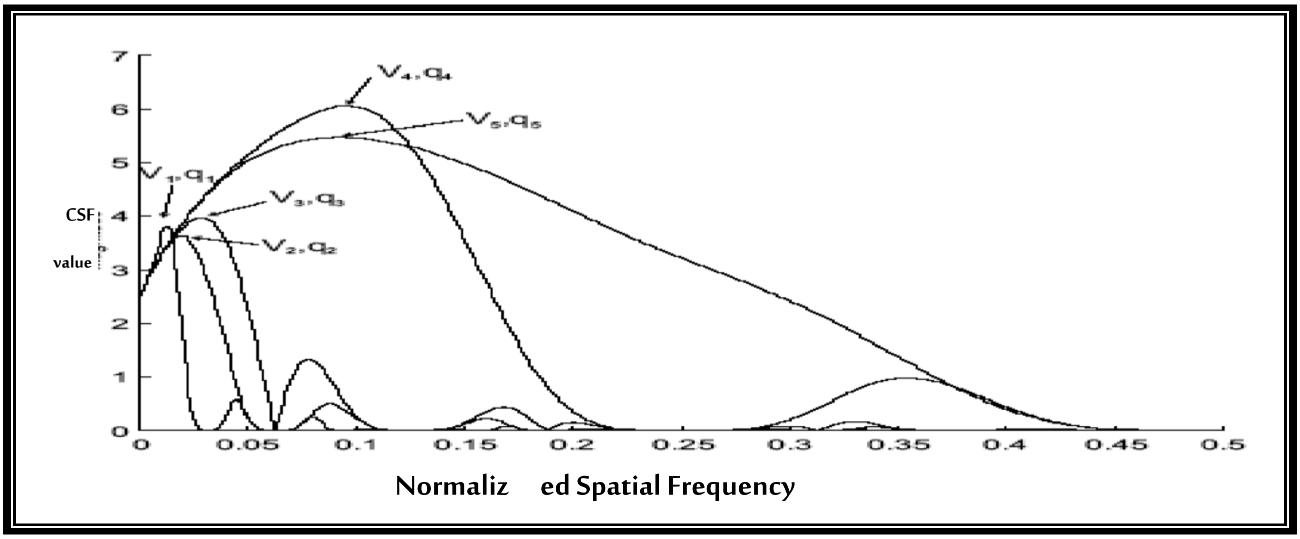

Fig (6) V subband 5-level wavelet decomposition of CSF 11-weight mask

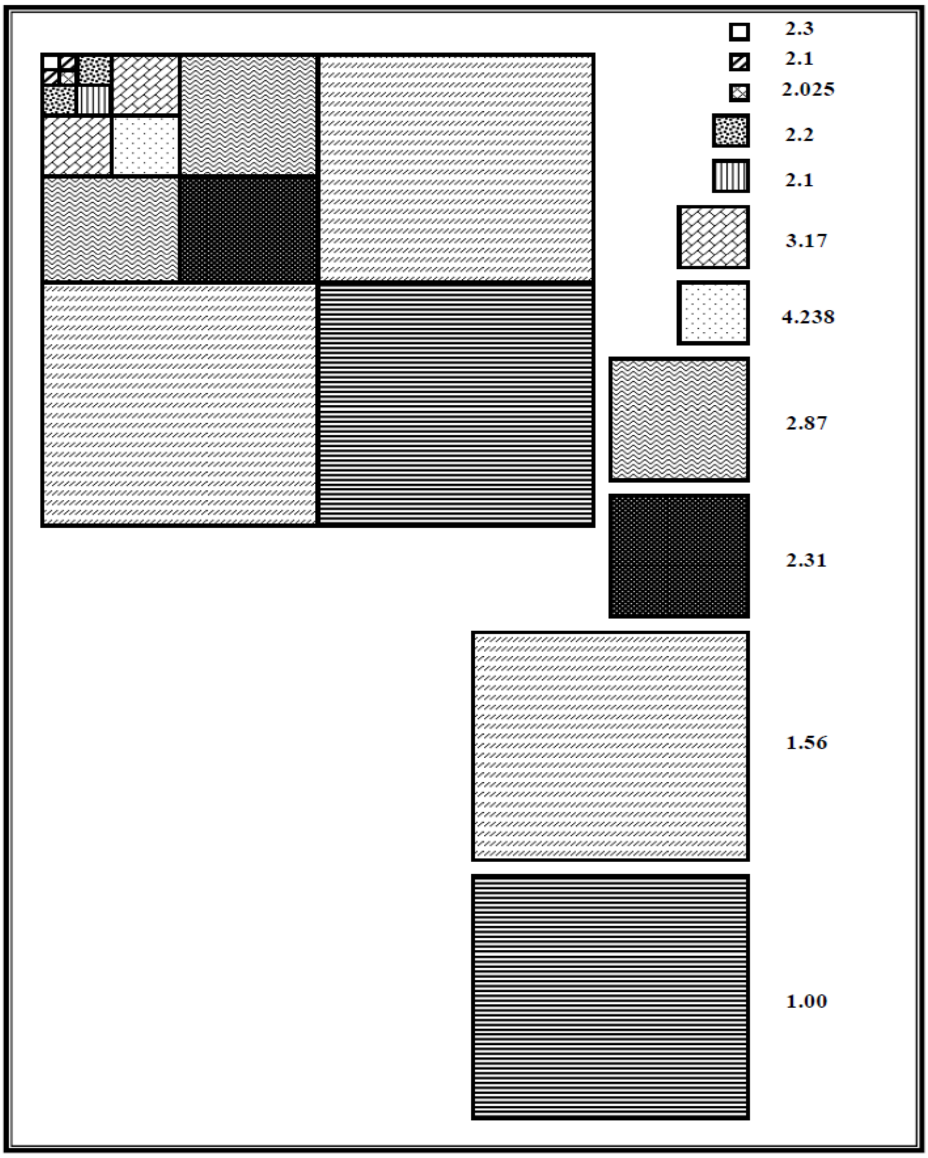

Fig (7) DWT CSF mask with modified 11unique weights

3- Implementations and Experimental Results.

3.1. Performance Measures Definitions:

The standard method for quantitatively comparing a compressed image with the origenal image is the *peak signal-to-noise ratio* ***(PSNR)*** [13**]** and [6]. In addition, we present a new subjective correlation criterion between the PSNR quality and **HVS** ***on*** based on the correlation measure between two compressed images (A) and (B)**.** With five observers, we evaluate the image view quality. The followings are the evaluation steps for this subjective quality correlation criteria:

1. If the improvement of PSNR values from compressed image(A) to compressed image(B) is more than 0.01 dB (Decibels), quality of PSNR is set to (1); if the improvement of PSNR is equal or less than 0.01 dB, quality of PSNR is set to(0).

2. If more than three observers are looking at the compressed image(A), while **HVS *on*** with better display than the compressed image(B), **HVS *on*** quality is set to (1); If less than three observers are looking at the compressed image(A) while **HVS *on*** with worse display than compressed image(B), **HVS *on*** quality is set to (0).
3. The correlation evaluation for different PSNR qualities and **HVS *on*** qualities are tabulated as Table 1.

Table (1) different between PSNR qualities and HVS *on* qualities

PSNR quality	HVS on quality	Correlation grads
1	1	Good
1	0	Negative mid good
0	1	Positive mid good
0	0	Worse

Finally, these image quantitive measures for compressed images will be applied in order to estimate the desired performance of the methods under investigation in this paper. Note that the image evaluated its quality on screen of computer.

The implementations in this paper, consists of several experiments. Some of these experiments compare the wavelet-image compression with two filters: Bio 6/8 and CDF 9/7 filters. These filters will be applied on different gray scale and color images with two color models: YCbCr and opponent spaces. After that, the opponent space results will be compared with those of the YCbCr space.

It can be easily seen, that the proposed 11-weight DWT CSF mask is a good method for CSF masking as compared with the classical methods (DWT CSF with 6 unique weights and 11 unique weights). From Fig. 8 a, b, and c, the CAT image with the proposed 11-weight DWT CSF mask that has PSNR values of 0.4 dB more than the classical 11-weight DWT CSF mask, and approximately 1 dB more than the classical 6-weight DWT CSF mask. In this paper, CSF masking experiments will use the proposed 11-weight DWT CSF mask, and 6-weight with band –average CSF mask or with peak CSF mask.

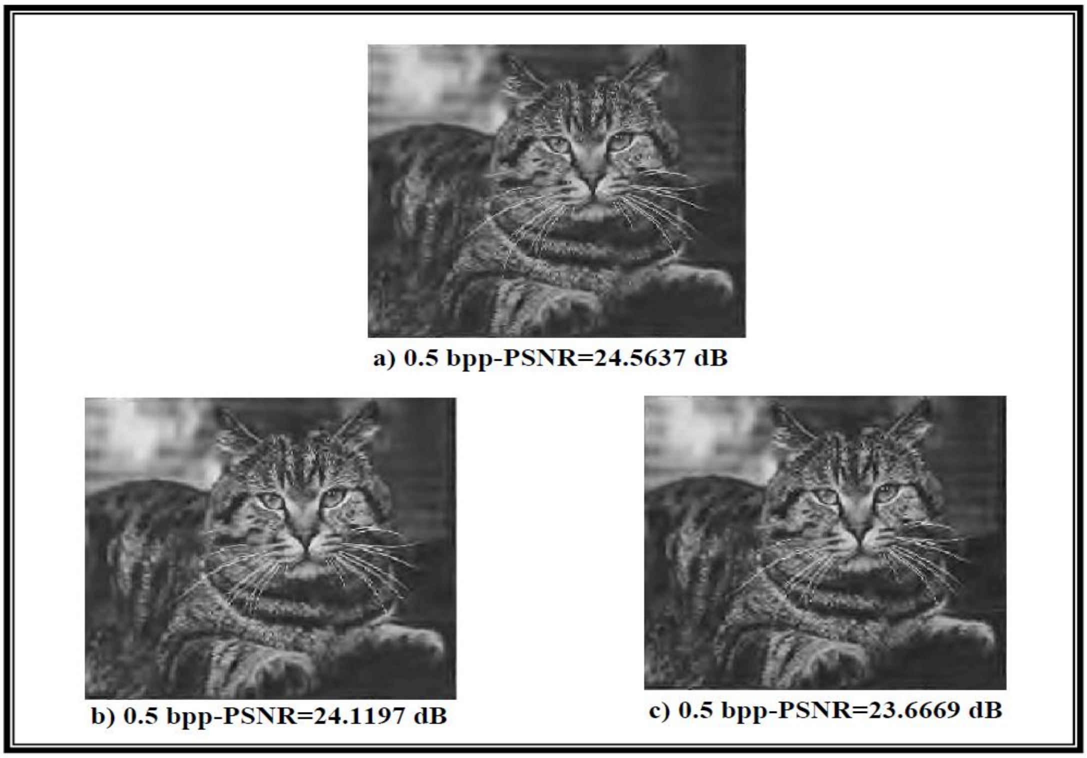

Fig (8) a) CAT compressed image with the proposed DWT CSF with 11-weights

b) CAT compressed image with the classical DWT CSF with11-weights

c) CAT compressed image with the DWT CSF with 6-weights

The experiments will also compare these three methods of CSF masking in gray scale and opponent space. In addition, the results of the proposed DWT CSF mask will show the differences between the cases of ***CSF/ON*** and ***CSF/OFF*** (i.e. applying CSF mask or not). These results will also show the difference of applying CSF mask on luminance component only, and applying it on all components (luminance and chrominance). Finally, the whole proposed wavelet-image compression method is compared with the standard-JPEG2000.

Different gray scale images; and color images with opponent space will be examined, in this comparison. In all these results, PSNR and **HVS *on*** will be used as indications for measuring differences between all comparing cases.

To simplify the explanations of the results, if CSF masking and asymmetric compression are both on, then the trial will be described as ***"CSF/ON"***. If CSF masking and asymmetric compression are both off, then the example will be described as ***"CSF/OFF"***. It should be noted here, that in all the following conditions, if it is not indicated, the correlation evaluations of the resulting compressed images are of grade ***"Good"***; otherwise, any other grade base will be indicated.

3.2 Different CSF Masking Methods:

The opponent space and Bio 6/8 filter will be applied to all CSF masking methods on five gray scale images and three color images. CSF/1 will refer to peak CSF method, CSF/2 will refer to band average method, and CSF/3 will refer to the proposed DWT CSF masking. Note that all CSF masking methods are applied in this section on L component in opponent space only.

Table 2 shows the values of PSNR (in dB) of LENA compressed images after applying three masking methods. LENA compressed images with CSF/1, CSF/2, and CSF/3 are shown in Fig. 9. CSF/3 are improved more than CSF/2 and CSF/1. Improvement by 0.1 dB to 0.6 dB is obtained with CSF/3 at bit rate of 0.5 bpp. It should be noted here the correlation qualities are determined for such compressed images at grade " ***Negative mid good*** ".

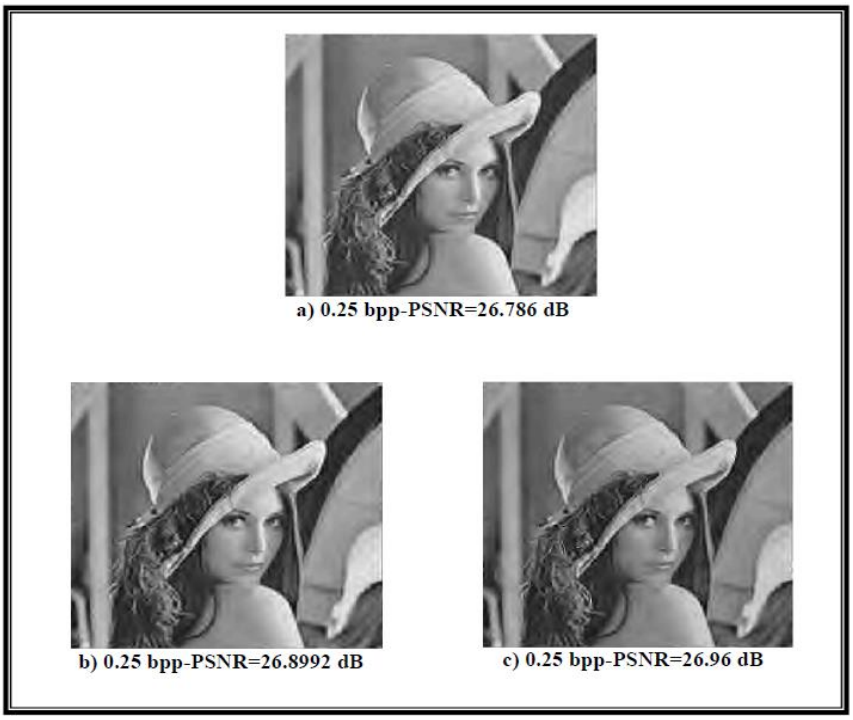

Fig 9 a) LENAimage with CSF/1

b) LENA image with CSF/2

c) LENA image with CSF/3

Table (2) PSNR' s (in dB) results of LENA image with CSF/1, CSF/2, and CSF/3

Bit Rate (bpp)	PSNR(dB) with CSF/1	PSNR(dB) with CSF/2	PSNR(dB) with CSF/3
0.25	26.7860	26.8992	26.9600
0.5	28.2149	28.8009	29.4257
1.0	31.1971	32.3292	32.7029

3.3 Images with CSF/ON and CSF/OFF:

Table 3 shows the City compressed image with or without CSF masking. The CSF masking effects on this image are shown in Fig. 10, which display City image with ***CSF/OFF*** and ***CSF/ON***. Although, the values of PSNR are reduced, the CSF/ON case (Fig. 10 b) shows the image with less noise and blurring than those in Fig. 10 a. The compressed images of Fig. 10 takes the grade ***"Positive mid good"***.

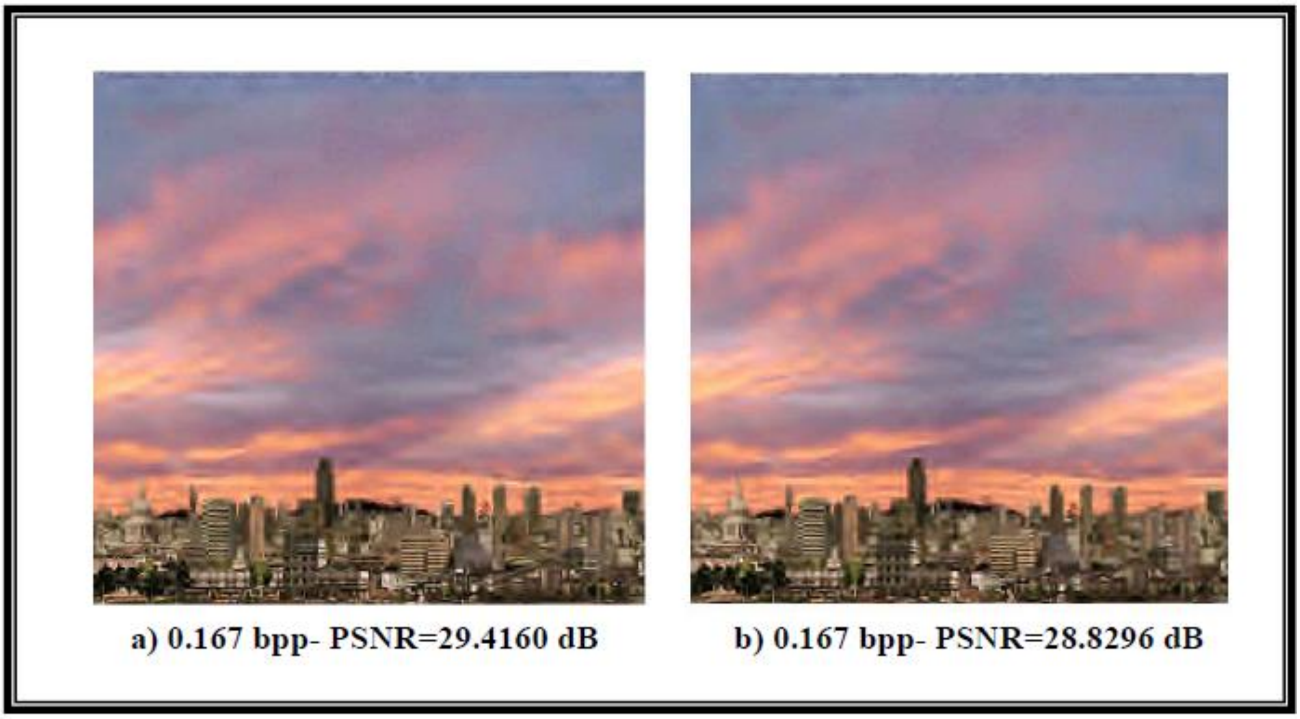

Fig. 10 a) City compressed image with CSF/OF

b) City compressed image with CSF/ON

Table (3) PSNR' s (in dB) results of City image, with CSF/ON and CSF/OFF

Bit Rate (bpp)	PSNR(dB) with CSF/OFF	PSNR(dB) with CSF/ON
0.167	29.4160	28.8296
0.25	33.9145	32.6323
0.417	39.4835	37.9093
1.0	57.5238	57.5238

3.4 Opponent space vs. YCbCr space:

Table 4 shows the values of PSNR of Flowers image. Opponent space with CDF 9/7 filter improves PSNR values by more than those compressed images in YCbCr space with Bio 6/8 filter. The difference in performance between the two-compressed images is in the range of 0.5 dB to 15 dB. The same previous reason for high differences in performance can be stated. Flowers compressed images in YCbCr space and in opponent space are shown in Fig 11.

a) 0. 167 bpp- PSNR=25.5181 dB

b) 0.167 bpp- PSNR=26.0805 dB

Fig 11 a) Flowers image with YCbCr& Bio 6/8 filter

b) Flowers image with opponent & CDF 9/7 filter

Table (4) PSNR' s (in dB) results of Flowers image, with YCbCr and opponent spaces

Bit Rate (bpp)	PSNR(dB) with YCbCr	PSNR(dB) with Opponent
0.167	25.5181	26.0805
0.25	28.9834	30.0399
0.417	33.5672	35.963
1.0	38.4603	54.6449

3.5 The improved Compression Method vs. JPEG2000:

In this section, the compressed images by the proposed DWT compression method is compared with standard-JPEG2000 method. We will take a single gray scale image and two color images as examples in opponent space with Bio 6/8 filter. The effect of two compression methods on each image is obtained. We will use the compression ratio ***CR*** formula to find JPEG 2000 performance.

Figure 12 shows the compressed images for the two methods: the proposed wavelet image compression and JPEG2000. Table 5 shows the bit rates, CR, and PSNR values for HELEN compressed images. Figure 12 shows HELEN compressed images; Figs. 12 a1, b1, c1, and d1 are for the proposed image compression method, Figs. 12 a2, b2, c2, and d2 are for the standard compression method-JPEG 2000.

Fig 12 HELEN image with wavelet image compression (a1,b1,c1,d1) & JPEG 2000 (a2, b2, c2, d2)

Table (5) Bit rates, and CR values with color images for HELEN image

Bit Rate (bpp)	Compression Ratio(CR)	PSNR(dB)for The proposed compression	PSNR(dB)for The JPEG2000
0.167	48.00: 1	32.3695	28.3847
0.25	32.00: 1	35.4965	30.096
0.417	19.20: 1	39.1642	32.0183
2.75	2.91: 1	54.6449	40.7770

It can be seen here, that the proposed image compression method improves the PSNR values for the HELEN images. The improvements of the proposed compression method are between 4 dB to 14 dB in HELEN image. In addition, wavelet image compression with opponent space remove noise and blurring and improves the view of all images.

Conclusions.

This paper provides a comprehensive evaluation of a modified CSF model for wavelet-based compression of gray scale and color images.

For gray scale images, the proposed 11-weight DWT CSF with has improved the PSNR values in most images. The correlation quality has also been improved. In LENA' s gray scale image, the correlation quality with PSNR and **HVS *on*** has appeared with the grade ***"negative mid good"***.

In opponent space color images, the correlation quality has also been shifted to the ***"positive mid good"***. That because the effect of masking method has reduced the PSNR values. However, the effect of CSF masking on views of images is very good. The CSF masking has removed noise and blurring which are the biproducts of the compression process. For color images, the opponent space has a better PSNR performance than YCbCr space. The correlation quality has the grade ***"good"***. In addition, in opponent space, the performance of the views of compressed images are better than those in YCbCr space.

It has been shown in this paper that the proposed DWT image compression method is better than standard compression method-JPEG2000. For color images, the correlation quality also has the grade ***"good"***. The improvements in PSNR values in the proposed DWT image compression method are better than those in JPEG2000. They have approximately values in the range 2 dB to 15 dB. In addition, the proposed DWT image compression method has improved the views of the color images and has removed noise and blurring, which have been not formatted during the other compression method. Finally, the accuracy of the results can be judged over a wide range of PSNR values that because these values have been increased with the increase of the bit rate which is exactly what is expected from the response of such compression.

Recommendations.

There are many directions that can be developed from the work of this paper. These future work directions are:

1. The CSF masking operation presented in this thesis has been applied to wavelets. It is believed that the same idea can be extended to wavelet packets. Constructing and applying a CSF mask to wavelet packet decomposition will provide quantitative and qualitative improvements similar to or even better than what have been obtained in this paper.
2. The same HVS compression ideas used here for still images may provide similar improvement for digital video compression. CSF masking is a simple operation that can be applied on a frame by frame basis while adding minimal computational overhead.
3. To investigate the performance of biorthogonal wavelet transforms; there are two other filters that can be applied; the first is the biorthogonal "Bio 9/7" filter and the second is the recently introduced biorthogonal "Bio 22/14" filter.

4. Implementation results can be improved by using some additional entropy coding besides the proposed method.

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