Wavelet Based Fuzzy Perceptual Mask For Images

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***Abstract*—One of the characteristics of the Human Visual System (HVS) is to model the sensitivity of the human eye at each coordinate location in the image. This paper explores the use of fuzzy logic for building a non-linear HVS model for perceptual masking in wavelet domain. The fuzzy input variables corresponding to brightness, edge sensitivity, and texture are computed for each wavelet coefficient at different scales in an image. The output of the fuzzy system is a single value which gives a perceptual value for each corresponding wavelet coefficient. This paper proposes a novel method of constructing perceptual mask in wavelet domain using fuzzy logic.**

I. Introduction

Watermarking and compression are complementary problems in image processing. A robust watermarking scheme should add as much watermark as possible in the host image without causing perceptual distortion. On the other hand, a high compression ratio scheme should remove as much information as possible without causing perceptual distortion. The common approach to solving both the problems in spite of conflicting requirements is to mapping the variation of the perception of the eye to the coordinate location of the pixels in image. This paper addresses these needs by constructing a novel perceptual mask. Weighting of coefficients or masking according to psycho visual considerations in spatial or spatial frequency domain is commonly used in various image processing applications including compression and watermarking. For example, JPEG2000 applies a fixed visual weighting of wavelet coefficients for compression. Perceptual Masks based on human visual system (HVS) are known to enhance performance. Human Visual System (HVS) models have several other applications including detecting color resolution in televisions, and detecting motion sensitivity for tracking objects. In this paper, the scope is restricted to modeling the sensitivity of the human eye at each coordinate location in the image by designing a perceptibility mask. To evaluate the effectiveness of the perceptual mask, an invisible watermark is inserted in the image which does not cause perceptual distortion to the human eye. The perceptual mask is also be used to determine the quantization level for visually lossless compression of the image without causing distortion.

II. Related Work

There is a current trend towards approaches that exploit psycho-visual information in images using human visual system (HVS) such as in [1]. Such techniques use explicit information about the HVS to exploit the limited dynamic range of the human eye. HVS models have been represented in spatial, spatial-frequency and wavelet domain. In [2], a nonlinear HVS model is represented by modeling the modulation transfer function (MTF) of spatial filters. Perceptual masks have also been constructed in DCT domain by modeling the Noise Visibility Function (NVF) [3]. HVS have been modeled as a function of spatial frequency and orientation in wavelet domain [4]. In [5], human visual characteristic were analyzed by weighting wavelet coefficients in different sub bands according to contrast sensitivity function (CSF). Lewis *et al* [6] proposed a HVS model in wavelet domain taking in account psycho visual considerations to evaluate the optimum weighting factor for each wavelet coefficient for quantization. Barni *et al* in [7], extended the model developed in [6] for watermarking. In [8], Barni's model was enhanced by computing the generalized Gaussian distribution (GGD) of the weights. However, there is no published work which combines these factors, which determine the optimum perceptual weight, using easy to understand lingusitic IF-THEN-ELSE rules. This paper proposes a novel method to build a simple nonlinear model of HVS perceptual masking using fuzzy logic in the wavelet domain. Fuzzy Logic has been used in the past for watermarking [9], [10], [11], [12]. Watermarking scheme based upon human visual mask in the DCT domain and fuzzy logic technique have also been investigated in [13]. The novelty of our algorithm is in constructing a fuzzy perceptual mask (FPM) which fuses texture, edge sensitivity and luminance content of the wavelet sub bands. FPM is the same size as the image since the weighting factor corresponding to each location in the image is computed for each wavelet coefficient.

The fuzzy perceptual mask construction uses the membership functions based on the work by Barni *et al*. The proposed method uses fuzzy logic to compute fuzzy perceptual model for data fusion instead of using algebraic operations such as addition or multiplication as done in the previous approaches. This fuzzy perceptual mask can also be used for other image processing applications which use HVS.

III. Fuzzy Perceptual Mask (FPM)

Step 1: Decompose the image using discrete wavelet transform (DWT) up to four levels using Debauchies-6 filtering kernel. I_l^θ is the sub band at resolution level $l = 0, 1, 2, 3$ and with orientation $\theta \in 0, 1, 2, 3$ (see Fig. 1).

Step 2: The fuzzy inputs corresponding for each wavelet coefficient are computed. This model exploits the limitation of the human eye using three major components required for perceptual masking i.e brightness, edge and texture sensitivity.

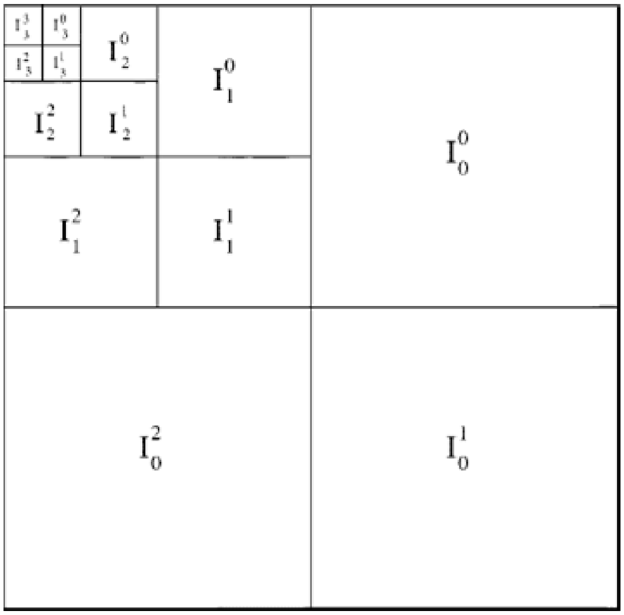


Fig. 1. Decomposition of an image in four resolution levels using DWT

a. Brightness sensitivity: This term takes into account the local brightness based on the magnitude of the scalar coefficients of the approximation or LL sub band.

$$L(l,i,j) = \frac{1}{256} I_l^3 \left(1 + \frac{i}{2^{3-l}}, 1 + \frac{j}{2^{3-l}}\right) \tag{1}$$

$$\begin{aligned} L^{'}(l,i,j) = & \quad 1 - L(l,i,j) \quad , if L(l,i,j) \leq 0.5 \\ = & \quad L(l,i,j) \quad , otherwise \end{aligned} \tag{2}$$

b. Texture parameter: This term is composed of local variance of the reconstructed LL sub band. This contribution is computed in a small $2x2$ neighborhood corresponding to the location of the wavelet coefficient.

$$T(l,i,j) = \sum_{x=0}^{1}\sum_{y=0}^{1} Var\left\{ I_l^3 \left(1 + y + \frac{i}{2^{3-l}}, 1 + x + \frac{j}{2^{3-l}}\right)\right\} \tag{3}$$

c. Edge sensitivity: The innermost term in the equation corresponds to the local mean square value of the DWT coefficients in all detail sub bands. Again, these contributions are computed in a small neighborhood corresponding to the location of the coefficient.

$$S(l,i,j) = \sum_{k=0}^{3-l} \frac{1}{16^k} \sum_{\theta=0}^{2}\sum_{x=0}^{1}\sum_{y=0}^{1} \left[I_{k+l}^{\theta} \left(y + \frac{i}{2^k}, x + \frac{j}{2^k} \right) \right]^2 \tag{4}$$

Step 3: The above computed values are fed as fuzzy inputs to the MAMDANI type fuzzy interference system as shown in Fig. 2.

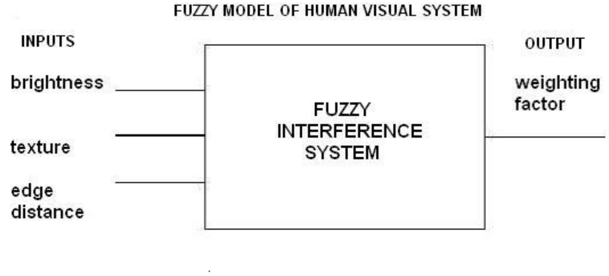
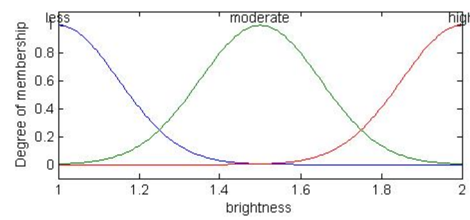


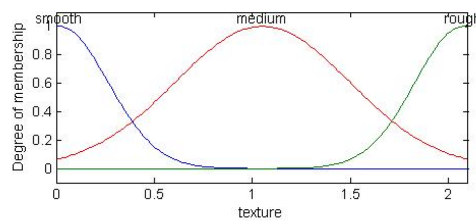
Fig. 2. Block diagram of Fuzzy Inference System (FIS)

Fuzzy Input Variables

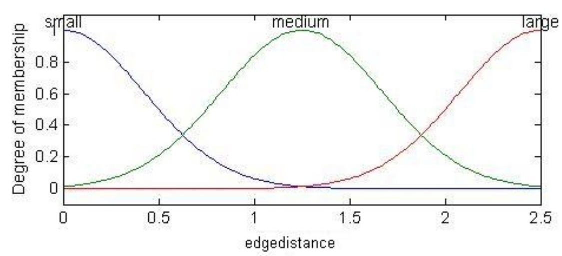
1. Brightness sensitivity of the eye (dark,medium,bright).



2. Texture sensitivity of the eye (low,medium,high).

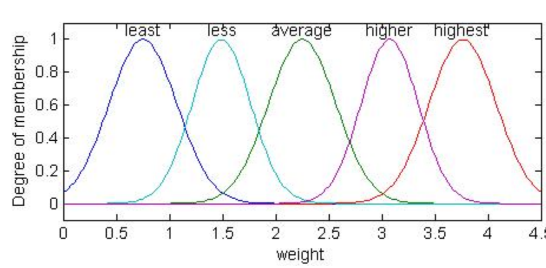


3. Edge distance or edge sensitivity (small,medium,large).



Fuzzy Output Variables

1. W=Weighting Factor [least,less,average,higher,highest]



Fuzzy Rules
The fuzzy rules are derived are based on the following facts:
a. The eye is less sensitive to noise in those areas of the image where brightness is high or low.
b. The eye is less sensitive to noise in highly textured areas but, among these, more sensitive near the edges.
c. The eye is less sensitive in the regions with high brightness and changes in very dark regions.

A total of 20 such rules are developed, some of the most important rules are as follows:

[Rule 1] IF [Brightness factor] is LOW AND [texture factor] is SMOOTH and [Edge distance] is SMALL then weighting factor (W) is LEAST

[Rule 2] IF [Brightness factor] is LOW AND [Texture factor] is MEDIUM and [Edge distance] is SMALL then weighting factor (W) is MEDIUM

[Rule 3] IF [Brightness factor] is LOW AND [Texture factor] is SMOOTH and [Edge distance] is MEDIUM then weighting factor(W) is MEDIUM

The fuzzy outcome for each rule is aggregated into fuzzy output set. The weighting factor is obtained by defuzzifying the fuzzy output using Mamdani type inference system.

IV. Applications Of FPM

A. Watermarking

The algorithm for watermarking consists of insertion and extraction of watermark.

1) Watermark Insertion: Discrete Wavelet Transform (DWT) of the image is taken using Daubechies-6 wavelet to give multi-resolution sub bands. Fuzzy Perceptual Mask (FPM) is computed for each wavelet coefficient of the image. The value of the mask at each coordinate location in the image is equivalent of a weighting factor as used in Eq. 5. Wavelet coefficients are randomly selected among all the coefficients in I_l^θ band where level $l = 0, 1, 2, 3$ and with orientation $\theta \in 0, 1, 2$. The value of the selected wavelet coefficient is multiplied by the fuzzy perceptual weighting factor and further scaled by a salience factor of 0.001. Add the watermark sequence to the entire band using the following equation:

$$W_l^\theta(i,j) = I_l^\theta(i,j) + \alpha w_l^\theta(i,j) x_l^\theta(i,j) \quad (5)$$

where,
$\alpha = 0.001$,
w_l^θ = weighting factor computed by FPM,
x_l^θ = pseudo random binary sequence,
$l = 0, 1, 2, 3$ and orientation $\theta \in 0, 1, 2$.

Then compute inverse discrete wavelet transform (IDWT) of W_l^θ to get the watermarked image.

2) Watermark Extraction: The watermark extraction process involves three steps as follows:
Step 1: Compute the Daubechies-6 DWT of the watermarked image that has to be tested for attacks against the original image.
Step 2: Subtract the coefficients of the two images to obtain the watermark.

Attacks	Correlation Coefficient
Jpeg (50%)	0.835
Additive Gaussian Noise	0.916
Wiener Filtering	0.86
Rotation	0.822
Cropping And Scaling Down	0.783

TABLE I
Correlation for various attacks

Step 3: Correlate the original watermark (W) with the recovered watermark (W') to determine the authenticity.

The watermark extraction performance is evaluated by correlating coefficient's of the extracted watermark W' and the original watermark W. If correlated value is more than a threshold T, the watermarked image is considered authentic.

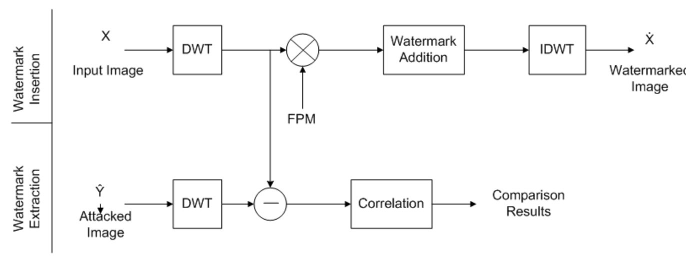


Fig. 3. Block Diagram for Applying FPM to Watermarking

B. Compression

After taking DWT of the image, FPM of the image is constructed. Quantization levels for each wavelet coefficient in the sub band are determined based on the fuzzy weights assigned by the mask. To further exploit redundancy, the quantized wavelet coefficients are Huffman encoded as well to get a bit stream as shown in Fig. 4

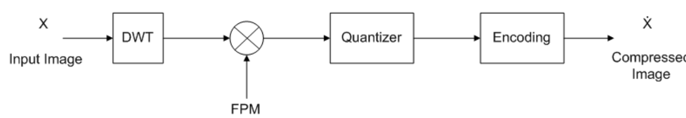


Fig. 4. Block Diagram for Applying FPM to Compression

V. Experimental Results

The images used covered a broad range of contents and types such as textured/smooth areas, size, synthetic, with straight edges, sharp, brightness/contrast, blur, etc. The image database used for testing can be obtained from the stirmark benchmark website. Experiments conducted to test the perception quality of the FPM were evaluated on the basis of the invisibility of the watermark to the human eye and the compression ratio for the images.

In Fig. 5.1, the original "Lena" image is presented, while in Fig. 5.2, the watermarked copy is shown; the images are evidently indistinguishable, thus proving the effectiveness of fuzzy logic based DWT watermarking. The watermark extraction results against various attacks such as JPEG compression,

Fig. 5. Watermarking Attacks

Image	Fuzzy Perceptual Mask	Barni	Variance Based Mask
Pepper	41.64	37.98	37.59
Boat	39.87	35.44	38.79
Airplane	40.73	35.87	41.13
Lena	40.52	35.76	41.31

TABLE II
MINIMUM PSNR GRANTING WATERMARK INVISIBILITY UNDER DIFFERENT MASKING STRATEGIES

quantization, additive noise, geometric distortions and filtering, are shown in Table I. Experimental results have shown that the proposed algorithm has excellent resistance against a wide range of attacks. It has been demonstrated in Table II that the proposed scheme has better robustness performance than Barni's schemes as well as other DWT-based watermarking schemes.

Experimental results for using FPM for compression are demonstrated in Fig. 6 and Table III.

Fig. 6. Compression

Image	Compression Ratio	PSNR(dB)	Mean Square Error
Lena	36.25	30.64	68.37
Pepper	36.25	29.75	72.53

TABLE III
SHOWS THE COMPRESSION RATIO FOR THE IMAGES USING FPM

VI. CONCLUSION

This paper has proposed using fuzzy logic to model HVS perceptual masking in wavelet domain. Fuzzy perceptual masks (FPM) have been developed with application to watermarking and compression without causing perceptual distortion. The fuzzy based watermarks are robust to attacks and at the same time achieve a high level of imperceptibility. The fuzzy based masks also achieve a high compression ratio without causing perceptual distortion. Future work will further explore the applications of FPM to motion tracking and edge detection. Other HVS characteristics such as color also need to be investigated as fuzzy inputs to the FPM.

REFERENCES

[1] C. Podilchuk and W. Zeng, "Image-adaptive watermarking using visual models," *Selected Areas in Communications, IEEE Journal on*, vol. 16, no. 4, pp. 525–539, May 1998.

[2] C. F. Hall and E. L. Hall, "A nonlinear model for the spatial characteristics of the human visual system," *Systems, Man and Cybernetics, IEEE Transactions on*, vol. 7, no. 3, pp. 161–170, March 1977.

[3] T. P. O'rourke and R. L. Stevenson, "Human visual system based wavelet decomposition for image compression," *J. VCIP V*, vol. 6, pp. 109–121, 1995.

[4] S. Belkacem, Z. Dibi, and A. Bouridane, "A masking model of hvs for image watermaking in the dct domain," in *Electronics, Circuits and Systems, 2007. ICECS 2007. 14th IEEE International Conference on*, Dec. 2007, pp. 330–334.

[5] A. Beegan, L. Iyer, A. Bell, V. Maher, and M. Ross, "Design and evaluation of perceptual masks for wavelet image compression," in *Digital Signal Processing Workshop, 2002 and the 2nd Signal Processing Education Workshop. Proceedings of 2002 IEEE 10th*, Oct. 2002, pp. 88–93.

[6] A. Lewis and G. Knowles, "Image compression using the 2-d wavelet transform," *Image Processing, IEEE Transactions on*, vol. 1, no. 2, pp. 244–250, Apr 1992.

[7] M. Barni, F. Bartolini, and A. Piva, "Improved wavelet-based watermarking through pixel-wise masking," *Image Processing, IEEE Transactions on*, vol. 10, no. 5, pp. 783–791, May 2001.

[8] Y. Gao, J. Wang, and S. Lian, "Optimum detection for barni's multiplicative watermarking in dwt domain," in *Communications and Networking in China, 2008. ChinaCom 2008. Third International Conference on*, Aug. 2008, pp. 1308–1311.

[9] T.-L. Y. Der-Chyuan Lou and M.-C. Chang, "Robust digital watermarking using fuzzy inference technique," *Journal of C.C.I.T*, vol. 32, no. 2, May 2004.

[10] A. M. David Coumou, "A fuzzy system solution for digital image watermarking," *IEEE Transactions on Consumer Electronics*, vol. 45, no. 4, pp. 1005–15, Nov 1999.

[11] S. P. Mohanty and K. Ramakrishnan, "An adaptive dct domain visible watermarking technique for protection of publicly available images," in *in Proceedings of the International Conference on Multimedia Processing and Systems, 2000*, 2000, pp. 19–5.

[12] T. B. and D. B, "Adaptive watermarking in dct domain," *Proceedings of IEEE International Conference on Acoustics, Speech and Signal Processing*, vol. 14, no. 4, pp. 1985–2988, 1997.

[13] N. Sakr, J. Zhao, and V. Groza, "A dynamic fuzzy logic approach to adaptive hvs-based watermarking," in *Haptic Audio Visual Environments and their Applications, 2005. IEEE International Workshop on*, Oct. 2005, p. 6.