Fuzzy Perceptual Watermarking For Ownership Verification

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Abstract - *An adaptive watermarking method based on the human visual system model and the fuzzy inference system in wavelet domain is proposed. Fuzzy logic is used for data fusion and builds a HVS model for spatial masking in wavelet domain. Modeling spatial masking is a complicated task and there is no single theoretical formulation to precisely compute the perceptual value for a corresponding wavelet coefficient. Fuzzy logic is used for data fusion and operates on the HVS model for spatial masking in wavelet domain. The fuzzy input variables (brightness, luminosity, texture) are computed for each wavelet coefficient in the image. The output of the fuzzy system is a single value which gives a perceptual value for each corresponding wavelet coefficient. The fuzzy based watermarks are robust to attacks and at the same time achieve a high level of imperceptibility.*

Keywords: watermarking, fuzzy logic, digital images.

1 Introduction

With the increase in the availability of digital data, there is a pressing need to manage and protect the illegal duplication of data. Image Watermarking is the technique of hiding an invisible signal in the image for authentication. The watermark inserted in the image should be irremovable and unalterable, and the change it introduces to the image should be imperceptible. A robust watermarking scheme should embed a watermark into the most perceptually significant regions of the host image. However, to be undetectable to the human visual system (HVS), a watermark must be located in the most perceptually insignificant regions of the host image. The two requirements are in direct conflict with each other. Thus, there is a need for an algorithm to insert high energy watermarks which are imperceptible at the same time. This paper addresses that need by constructing fuzzy perceptual masks.

2 Related Work

Watermarking can be grouped into two categories: spatial domain methods and frequency domain methods. Methods using wavelet domain for watermarking offer the highest information hiding capacity. There is a current trend towards approaches that make use of information about the human visual system (HVS) [2], to produce a more robust watermark. Such techniques use explicit information about the HVS to exploit the limited dynamic range of the human eye. Fuzzy Logic has been used in the past for watermarking [3], [4], [5], [6]. Fuzzy rules have been developed in the spatial domain to embed the watermark using gray scale distribution and texture as fuzzy inputs. Fuzzy inference filter has been used to choose entropy of wavelet coefficients to embed watermarks. Watermarking scheme based upon human visual mask in the DCT domain and fuzzy logic technique have been the main focus in the past related work. Barni et al. [7] propose a method to evaluate the optimum weighting factor for each DWT coefficient according to psycho visual considerations. In [7], weighting factor is composed by the product of two terms: the first is the local mean square value of the DWT coefficients in detail subbands at the first decomposition level which represent the distance from the edges, while the second is the local variance of the low-pass subband which gives a measure of texture activity in the neighborhood of the pixel. To fuse the information, Barni et al. decided to multiply the two terms, since the eye is less sensitive to changes in textured areas, but more sensitive near edges where as Lewis and Knowles [8] proposed to simply add the two contributions. This paper implements a simple model of HVS spatial masking using fuzzy logic in the wavelet domain. The algorithm constructs a fuzzy perceptual mask which fuses texture and luminance content of all the image sub bands. The mask is computed for each wavelet coefficient.

3 Proposed Method

The watermark insertion and detection algorithms are detailed in the following sub-sections.

3.1 Watermark Insertion

The algorithm for embedding the watermark in a host image is as follows:

Step 1: Decompose the original grayscale image 256x256 using DWT up to four levels using Debauchies6 filtering kernel. Call I_l^θ 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 using the modified psychovisual model given by Barni et al. This model exploits the limitation of the human eye using three major components required for spatial masking i.e. brightness, edge and texture sensitivity.

a. Brightness sensitivity: This term L takes into account the local brightness based on the gray level values of the low pass version of the image (Equation 1 and 2).

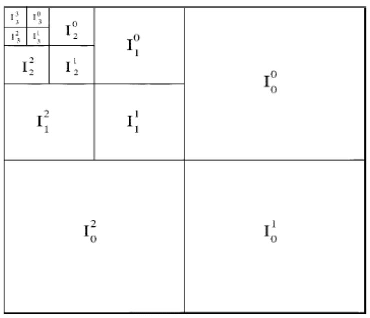


Fig. 1. Decomposition of an image in four resolution levels using DWT.

$$L(l,i,j) = \frac{1}{256} I_3^3\left(1+\frac{i}{2^{3-l}}, 1+\frac{j}{2^{3-l}}\right) \qquad \text{.......... (1)}$$

$$L'(l,i,j) = \begin{cases} 1-L(l,i,j), & \text{if } L(l,i,j) < 0.5 \\ L(l,i,j), & \text{otherwise} \end{cases} \qquad \text{.......... (2)}$$

b. Texture parameter: This term E is composed of local variance of the subband. This contribution is computed in a small 2*2 neighborhood corresponding to the location of the wavelet coefficient.

$$E_2(l,i,j) = \left[\sum_{x=0}^{1}\sum_{y=0}^{1} Var\left\{ I_3^3\left(1+y+\frac{i}{2^{3-l}}, 1+x+\frac{j}{2^{3-l}}\right)\right\}\right]^{0.2} \qquad \text{..........(3)}$$

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

$$E_l(l,i,j) = \left[\sum_{k=0}^{3-l}\frac{1}{16^k}\sum_{\theta=0}^{2}\sum_{x=0}^{1}\sum_{y=0}^{1}\left[I_{k+l}^{\theta}\left(y+\frac{i}{2^k}, x+\frac{j}{2^k}\right)\right]^2\right]^{0.2} \qquad \text{.......... (4)}$$

Step 3: The above computed values are fed as fuzzy inputs to a fuzzy interference system (FIS).

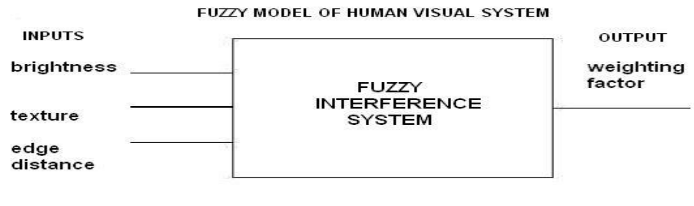


Fig. 2. Block diagram of Fuzzy Inference System (FIS)

Fuzzy input and output variables are plotted below.

Fuzzy Input Variables

1. Brightness sensitivity of the eye

The brightness can be categorized as dark, medium or bright. The figure below plots the fuzzy input variable with less, moderate and high brightness values.

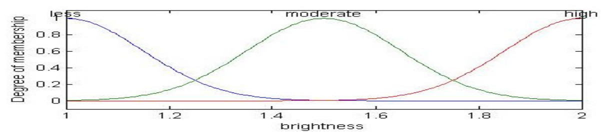


Fig. 3. Fuzzy Values for Brightness

2. Texture sensitivity of the eye

The eye's response to texture is classified into 3 categories - low, medium, and high. Plots below illustrate smooth, medium and rough texture values for this fuzzy input variable.

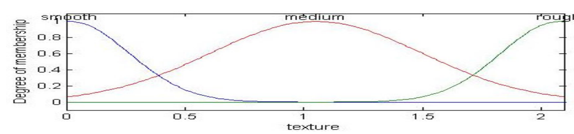


Fig. 4. Fuzzy Values for Texture

3. Edge distance or edge sensitivity

The edge distance can be small, medium, or large as shown in the plots below.

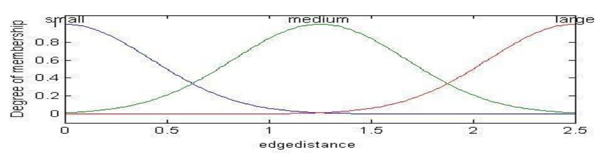


Fig. 5. Fuzzy Values for Edge Sensitivity

Fuzzy Output Variables

1. W=Weighting Factor

Output of the FIS is a weighting factor that can take the following values - least, less, average, higher, and highest. Plots for the values are shown in Fig. 6.

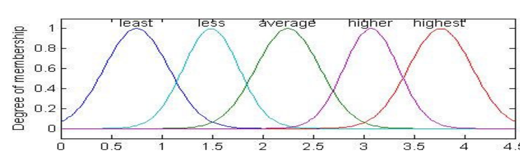


Fig. 6. Fuzzy Values for Edge Sensitivity

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, amongst 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 27 such rules are developed and are listed below:

[Rule 1] If *[Brightness factor]* is DARK and *[Texture factor]* is LOW and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 2] If *[Brightness factor]* is DARK and *[Texture factor]* is MEDIUM and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 3] If *[Brightness factor]* is DARK and *[Texture factor]* is HIGH and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 4] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is LOW and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 5] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is MEDIUM and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 6] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is HIGH and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 7] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is LOW and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 8] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is MEDIUM and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 9] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is HIGH and *[Edge distance]* is SMALL then *[Weighting factor]* is LEAST

[Rule 10] If *[Brightness factor]* is DARK and *[Texture factor]* is LOW and *[Edge distance]* is MEDIUM then *[Weighting factor]* is LESS

[Rule 11] If *[Brightness factor]* is DARK and *[Texture factor]* is MEDIUM and *[Edge distance]* is MEDIUM then *[Weighting factor]* is HIGH

[Rule 12] If *[Brightness factor]* is DARK and *[Texture factor]* is HIGH and *[Edge distance]* is MEDIUM then *[Weighting factor]* is HIGHER

[Rule 13] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is LOW and *[Edge distance]* is MEDIUM then *[Weighting factor]* is LESS

[Rule 14] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is MEDIUM and *[Edge distance]* is MEDIUM then *[Weighting factor]* is AVERAGE

[Rule 15] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is HIGH and *[Edge distance]* is MEDIUM then *[Weighting factor]* is AVERAGE

[Rule 16] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is LOW and *[Edge distance]* is MEDIUM then *[Weighting factor]* is LESS

[Rule 17] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is MEDIUM and *[Edge distance]* is MEDIUM then *[Weighting factor]* is AVERAGE

[Rule 18] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is HIGH and *[Edge distance]* is MEDIUM then *[Weighting factor]* is HIGHER

[Rule 19] If *[Brightness factor]* is DARK and *[Texture factor]* is LOW and *[Edge distance]* is LARGE then *[Weighting factor]* is LESS

[Rule 20] If *[Brightness factor]* is DARK and *[Texture factor]* is MEDIUM and *[Edge distance]* is LARGE then *[Weighting factor]* is HIGHER

[Rule 21] If *[Brightness factor]* is DARK and *[Texture factor]* is HIGH and *[Edge distance]* is LARGE then *[Weighting factor]* is HIGHEST

[Rule 22] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is LOW and LARGE then *[Weighting factor]* is LESS

[Rule 23] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is MEDIUM and *[Edge distance]* is LARGE then *[Weighting factor]* is AVERAGE

[Rule 24] If *[Brightness factor]* is MEDIUM and *[Texture factor]* is HIGH and *[Edge distance]* is LARGE then *[Weighting factor]* is HIGHER

[Rule 25] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is LOW and *[Edge distance]* is LARGE then *[Weighting factor]* is LESS

[Rule 26] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is MEDIUM and *[Edge distance]* is LARGE then *[Weighting factor]* is HIGHER

[Rule 27] If *[Brightness factor]* is BRIGHT and *[Texture factor]* is HIGH and *[Edge distance]* is LARGE then *[Weighting factor]* is HIGHEST

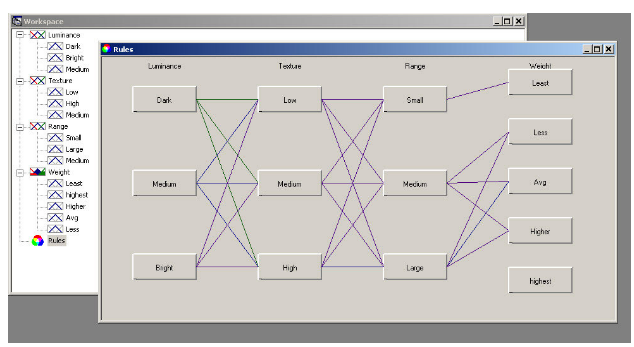


Fig. 7. Most Frequently Fired Rules in the Fuzzy Rule Engine

Step 4: The above procedure of computing the weighting factor is computed for the all the coefficients in I_l^{ϑ} band where level l=0,1,2,3 and with orientation $\vartheta \in \{0,1,2\}$.

Step 5: Add the watermark sequence W_l^{ϑ} to the entire I_l^{ϑ} band using the following equation:

$$W_l^{\vartheta}(i, j) = I_l^{\vartheta}(i, j) + \alpha w^{\theta}(i,j) \quad \ldots\ldots\ldots (5)$$

where, $\alpha = 0.001$

$w^{\theta}(i,j)$ = weighting factor computed by FIS

l = sub band at resolution level 0,1,2,3 and

$\vartheta \in \{0,1,2\}$ represents orientation

Step 6: Compute IDWT of W_l^{ϑ} to get the watermarked image.

3.2 Watermark Detection

A non blind method is used to extract the watermark. Algorithm for extracting the watermark is as follows:

Step 1: Compute the Daubechies-6 DWT of the 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.

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

The watermark extraction performance is evaluated by correlating coefficients of the extracted watermark W' and the original watermark W.

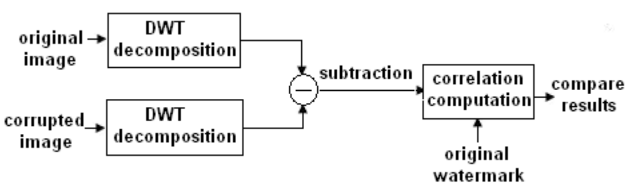


Fig. 8. Correlation of extracted watermark

4 Experiments and Results

A number of experiments were performed in developing the fuzzy interference system. Various membership functions were tried for the fuzzy input and output variables for triangular, trapezoidal, sigma and Gaussian curves. Different fuzzy rules were adopted and analyzed using fuzzy surface plots.

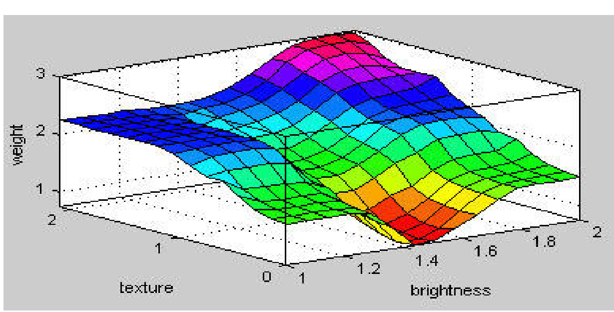


Fig. 9. Fuzzy Surface plot for texture and brightness

Fig. 9. shows cross plotting fuzzy inputs, texture against brightness to show the non-linear relationship between the variables. 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. In Fig. 10.1, the original "Lena" image is presented, while in Fig. 10.3, the watermarked copy is shown.

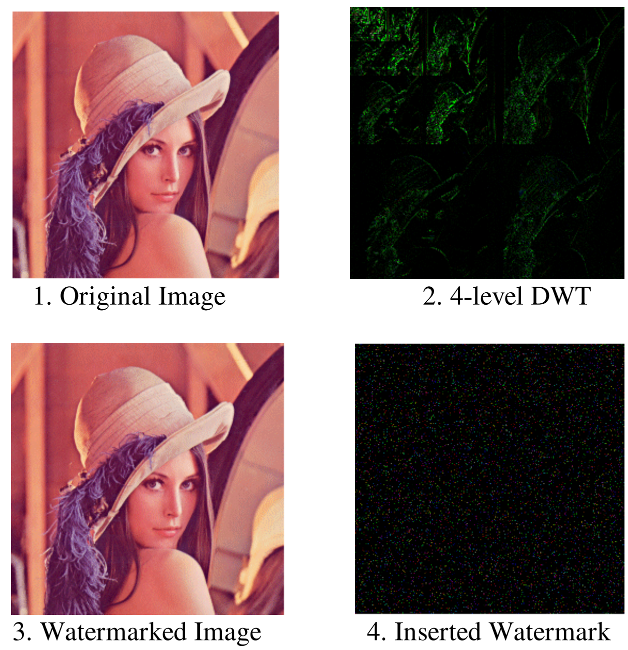


Fig. 10. Watermarking of Lenna Image

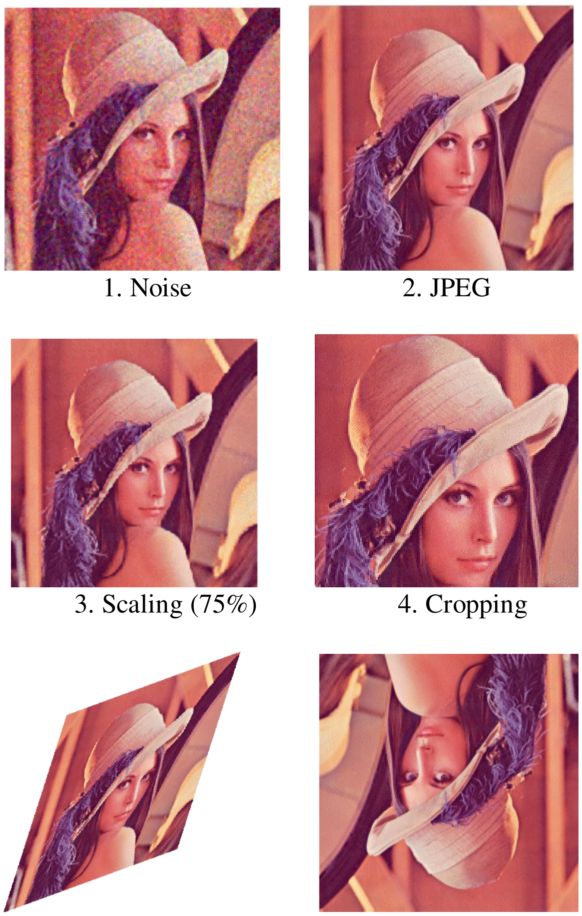
Table 1. Minimum PSNR granting watermark invisibility under fuzzy masking strategy

Test Image	*PSNR (dB)*
LENA	*41.53*
BOAT	*39.67*
AIRPLANE	*40.98*
PEPPER	*40.21*

Extensive experiments were conducted in order to demonstrate the robustness of the algorithm to various attacks such as compression, affine transformations, noise addition, filtering, cropping and scaling (Fig. 10). A benchmark called Checkmark was adopted to test effectiveness of the proposed method against various attacks. Correlation results of extracted watermark with the inserted watermark have been tabulated in Table 2.

Table 2. Correlation for various attacks

Attacks	*Correlation results*
JPEG (50%)	*0.845*
Noise	*0.912*
Wiener Filtering	*0.88*
Rotation	*0.854*
Cropping	*0.823*
Scaling	*0.796*



1. Noise 2. JPEG 3. Scaling (75%) 4. Cropping 5. Rotation

Fig. 10. Watermarking Attacks

5 Conclusions

This paper has proposed using fuzzy logic to model HVS spatial masking in wavelet domain. Fuzzy perceptual masks have been developed which allow high density and high energy watermarks. The fuzzy based watermarks are robust to attacks and at the same time achieve a high level of imperceptibility. Wavelet maxima with zero tree structures can be further added as input fuzzy variables and exploited to build a more sophisticated model. This work can be further extended to fragile watermarks and blind watermarking.

6 References

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