Multi Block based Image Watermarking in Wavelet Domain Using Genetic Programming

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Abstract: *The increased utilization of internet in sharing and distribution of digital data makes it is very difficult to maintain copyright and ownership of data. Digital watermarking offers a method for authentication and copyright protection. We propose a blind, still image, Genetic Programming (GP) based robust watermark scheme for copyright protection. In this scheme, pseudorandom sequence of real number is used as watermark. It is embedded into perceptually significant blocks of vertical and horizontal sub-band in wavelet domain to achieve robustness. GP is used to structure the watermark for improved imperceptibility by considering the Human Visual System (HVS) characteristics such as luminance sensitivity and self and neighbourhood contrast masking. We also present a GP function which determines the optimal watermark strength for selected coefficients irrespective of the block size. Watermark detection is performed using correlation. Our experiments show that in proposed scheme the watermark resists image processing attack, noise attack, geometric attack and cascading attack. We compare our proposed technique with other two genetic perceptual model based techniques. Comparison results show that our multiblock based technique is approximately 5%, and 23% more robust, then the other two compared techniques.*

Keywords: *Robust watermark, GP, wavelet domain, digital watermarking, HVS.*

Received January 23, 2013; accepted June 4, 2013; published online March 13, 2014

1. Introduction

Digital watermarking is gaining popularity as a mean to effectively deal with copyrights and ownership issues, access control and broadcast monitoring. Watermarking techniques can be mainly divided into two types: Robust watermarking and fragile watermarking. In robust watermarking techniques, any attempt to remove or temper, embedded ownership information in the host object is resisted whereas fragile watermarking is used for verification/authentication purposes. Fragile watermark can easily be destroyed even by small modifications or manipulations.

Mainly two types of watermarks are used to present ownership information: The form of numerical sequences, that are usually randomly generated and in the form of an image/logo or shape/mark/text etc., that can be used to identify the originality of that multimedia object.

Watermarking algorithms are usually designed in two domains [19]: Spatial domain [3, 4, 16, 23] and transform domain, also called frequency domain [7, 11, 15, 18]. In spatial domain, the information is added directly in pixel value while in transform domain, the information is embedded in the coefficient after transforming the pixels either by using Discrete Cosine Transformation (DCT), Discrete Fourier Transformation (DFT) or Discrete Wavelet Transformation (DWT). The watermark is usually embedded in middle frequency part of the image. As changes made to low frequency part i.e., LL sub-band can easily be visible to human eye, while the high frequency part i.e., HH sub-band is more sensitive to compression and scaling operation. The main requirement of a watermarking system is imperceptibility and robustness. But, these requirements cannot be obtained at same time as both properties are complement to each other and offer a trade-off. When we increase one, the other decrease and vice versa. Therefore, a compromise between these characteristics needs to be found to achieve the optimal level of watermark strength. A number of different block based watermarking techniques have been proposed in literature [6, 19].

In this paper we propose a multi-block watermarking technique. A similar work addressing watermarking imperceptibility versus robustness issue using Genetic Programming (GP) with an image block of size only 4 has been discussed in [1]. The proposed technique uses GP to generate perceptual mask of gray scale images in DWT domain. In this work, GP is trained to embed imperceptible watermark using block sizes of 4, 8, 16, 32. Therefore, the proposed technique can embed watermark in an image using any these block sizes. Perceptual significance of coefficients is calculated in the DWT domain to get high level of robustness. Coefficients selected for watermark embedding are scattered throughout the image, which makes it more robust. We employ JPEG2000 Perceptual Model, to embed watermark imperceptibly. Experimental results show significant improvement in the imperceptibility of watermark for different block sizes and considerable enhancement in the robustness under different attacks.

GP is an evolutionary computation technique which gets its inspiration from natural selection and biological evolution processes [10]. We provide the desired output to GP that takes its operands, operators and a fitness function to generate candidate optimal solutions of the given problem. Fitness of candidate solution is measured by the fitness criteria specified by the user. GP works iteratively and stops when it finds either an optimal solution or when it reaches user specified number of iterations/generations as shown in Figure 1. The output solution is usually in the form of a tree.

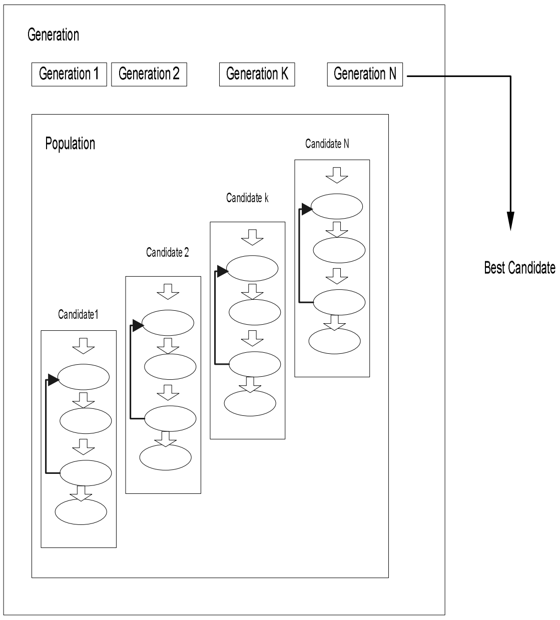

Figure 1. GP Simulation for evolving best candidate.

The rest of the paper is organized as follows: In section 2, we present some related work. In section 3, we provide details of our proposed technique. Section 4 describes implementation measures. Section 5 demonstrates various experimental results and comparisons between existing and proposed GP based watermarking techniques. Conclusions are presented in section 6.

2. Related Work

Piva *et al.* [18] proposed a technique in which embedding is performed in the DCT domain. In this technique, zigzag scan DCT coefficients are obtained in a vector form and the first $(l+m)$ coefficients are selected, where l and m represent integers and $l+m$ represent a range of coefficients selected for watermark embedding. To compensate trade off between robustness and imperceptibility, the last m coefficients are selected for embedding. Detection of watermark is performed using correlation.

Usman *et al.* [22] introduced a technique for visual tuning of a watermark that is made in DCT domain. GP is used for watermark structuring on the basis of cascading attack and HVS characteristics. Bose, Chaudhuri, and Hocquenghem (BCH) codes are used to encode the message. Woo *et al.* [24] proposed a simplified embedding technique that significantly reduces the embedding time while preserving the performance of imperceptibility and robustness. This fast embedding technique exploits implicit features of DWT sub-bands to mimic HVS characteristics. While considered imperceptibility, robustness and capacity for watermark embedding, Huang *et al.* [8] proposed a technique that uses GA to select appropriate coefficient position using trade off between these three factors. Then, binary watermark is embedded in DCT domain. The drawback of this scheme is that it does not consider the appropriate level of watermark strength for each coefficient.

Singular Value Decomposition (SVD) based optimized watermarking technique for gray scale images to get optimal balance between robustness and imperceptibility has been proposed in [2]. GA is used to obtain optimal multiple scaling factors to get best level of robustness and imperceptibility. It uses Correlation method as a fitness function. In [12] a redistributed invariant wavelet domain has been proposed to resist geometric attacks, which can change the value of pixels such as rotation, flipping etc., In this scheme, authors have applied existing wavelet based techniques on redistributed invariant domain and show that the new domain is more resistant to geometric attacks.

Keyvanpour *et al.* [9] have proposed a dynamic blocking technique. In this technique, authors have proposed to select those pixels which are related to edges in DWT domain for watermark embedding. Robustness is achieved by embedding multiple copies of watermark.

To obtain robustness [13] suggest to randomly choosing blocks while keeping the local maxima relationship in a block by embedding watermark of different energy in different wavelet coefficients. To keep the secrecy of the embedding location of watermark, blocks of different sizes are used.

To increase the embedded watermark capacity, Peng *et al.* [17] propose a reversible data hiding technique, which can tune selected integer transform parameters such that it can adaptively embed the watermark, using the block type information. The block types are categorized according to some pre-estimated distortion.

Shen and Chen [21] suggest to consider all three important parameters of watermarking, i.e., robustness, capacity and imperceptibility. An improved pixel-wise masking model, based on dual watermarking technique is developed. They obtain robustness by embedding watermark in selected wavelet coefficients and due to the dual watermarking, the capacity of watermark increases.

To preserve affine transformation and to resist affine transformation attack, Yang *et al.* [25] propose a Code Division Multiplexing Algorithm (CDMA) based technique using Barycentric coordinate representation for the image in a discrete biorthogonal wavelet domain.

3. Proposed Technique

Our algorithm embed watermark in 2D-DWT domain. It works in two phases: Watermark embedding phase and watermark extraction phase. In Watermark embedding phase, as shown in Figure 2, an image X is transformed to first level discrete wavelet and embedding is performed in horizontal and vertical sub-bands in the wavelet domain. LH and HL bands are divided into independent, non overlapping $m\times m$ blocks, where m is an integer. In our technique, we set it to 4, 8, 16, and 32. Then, perceptual significance of each $m\times m$ block is calculated using the following formula [5]:

$$S=\sum_{i=1,j=1}^{i=m,j=m} H\left(i,j\right)^2 \tag{1}$$

Where H represent any block within the sub-band whose coefficients, *i, j* can be up to size defined by *m.* The sum of square of the selected coefficients in a block of size $m\times m$ is represented by S. Based on the value of S of Equation 1, blocks in the sub-band are arranged in ascending order. From the sorted list of blocks, b numbers of blocks are selected for the watermark embedding. Watermark is embedded in the selected coefficients using the following equation:

$$X'\left[i,j\right]=X\left[i,j\right]+\mid\mu\mid *W\left[i,j\right] \tag{2}$$

Where $X'[i, j]$ is the watermarked coefficient, $X[i, j]$ is the watermark generated by pseudo random sequence and $\propto$ is the HVS based function and represents perceptual mask of the selected watermark embedding coefficient. GP takes the luminance and contrast masking value for each of the selected coefficient in the 4, 8, 16 and 32 size blocks and determines the optimum value of the watermark. Using user specified selection criteria, GP iterates specified number of times until it gets best strength of watermark for the selected coefficient, balancing both the imperceptibility and robustness. In this way we get genetic perceptual mask using GP for the whole image with different block sizes.

In watermark detection phase, it is assumed that the user has advance knowledge of all steps performed for embedding data. Correlation method is used for the watermark detection. In second phase, watermarked image X' is decomposed into single level 2-Dimensional Wavelet Transform (DWT2). The HL, LH sub-bands are divided into $m\times m$ blocks. Sum of squares of coefficients are determined and sorted into descending order. From the sorted blocks, top b blocks are selected for the watermark detection purpose. The correlation between marked coefficient and the watermark is calculated using the equation:

$$C=\frac{1}{M}\sum_{i=1}^{M} y_i . t_i . \alpha \tag{3}$$

Where M is the total number of coefficient to be marked, y_i is the watermark; t_i is the image coefficient to be marked and α is the watermark level calculated through GP. Finally, correlation value C is compared to predefined thresholds to determine whether the watermark exists or not.

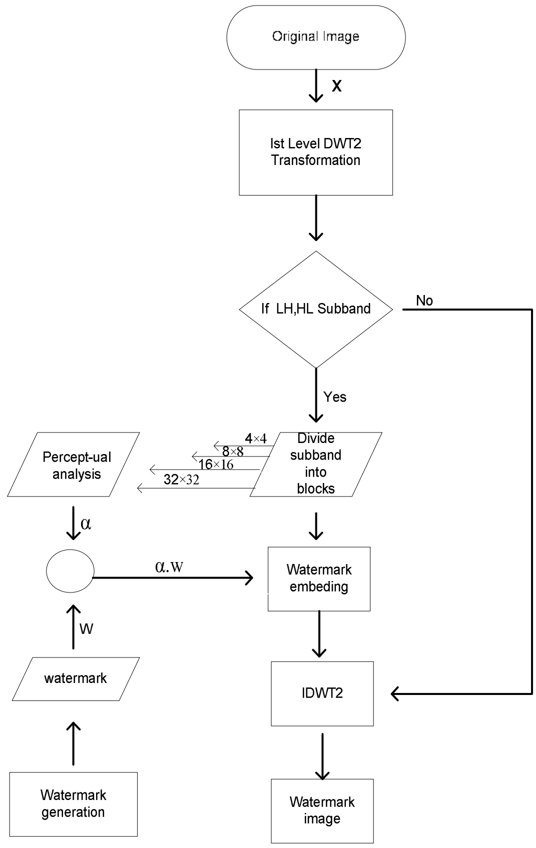

Figure 2. Multi block watermarking technique flow diagram. perceptual analysis part is performed by the GP.

3.1. Human Visual System HVS

A watermark is embedded using a perceptual model which exploits the characteristics of HVS to get the imperceptibility. In this technique, factors such as self contrast masking, neighbourhood contrast masking and luminance sensitivity are used. The strength of watermark which is to be embedded is control by HVS characteristics and in our technique is represented as:

$$\mu=f\left(a_l\left(\lambda,\theta,i,j\right),a_c\left(\lambda,\theta,i,j\right)\right) \tag{4}$$

Where a_l represent luminance factor/variable while a_c represent contrast masking parameter, which can further be categorized as self contrast masking and neighbourhood contrast masking. For each DWT transformed coefficient, at location *(i, j)* within suband

(λ, θ) where, λ is the transform level and θ is the orientation [14]:

$$a_l(\lambda,\theta,i,j) = \left(\frac{\hat{\vartheta}_{\lambda max,LL_{I,J}}}{\hat{\vartheta}_{mean}}\right)^{\alpha T} \tag{5}$$

$$\hat{\vartheta}_{\lambda max,LL_{I,J}} = \vartheta_{\lambda max},LL_{i,j} / Q_{\lambda max}.LL \tag{6}$$

$$\hat{\vartheta}_{mean} = \vartheta_{mean} / Q_{\lambda max}.LL \tag{7}$$

$$Q_{\lambda\theta} = JND_{\lambda\theta} \tag{8}$$

Now, we perform the luminance masking using Equation 5, where $\hat{\vartheta}_{\lambda \max,LL_{I,J}}$ is the coefficient value in LL sub-band that spatially corresponds to the location (λ,θ, i, j). This parameter controls the degree to which luminance masking occurs and $\propto T$ takes value of 0.649 as suggested in [14]:

$$a_c(\lambda,\theta,i,j) = a_{c\_self}(\lambda,\theta,i,j).a_{c\_neig}(\lambda,\theta,i,j) \tag{9}$$

$$a_{c\_self}(\lambda,\theta,i,j) = max\{1, \left(\frac{|\vartheta(\lambda,\theta,i,j)|}{JND_{\lambda\theta}al(\lambda,\theta,i,j)}\right)^{\varepsilon}\} \tag{10}$$

$$a_{c\_neig}(\lambda,\theta,i,j) = max\{1, \frac{\sum_{\kappa\varepsilon neighbourof(\lambda,\theta,i,j)} \left(\left|\frac{\vartheta(\kappa)}{JND_{\lambda\theta}al(\lambda,\theta,i,j)}\right|\right)}{N_{i,j}}\} \tag{11}$$

Next, we perform the contrast masking using Equation 9 where a_{c_self} (λ,θ, i, j) is self-contrast adjustment factor, while a_{c_neig} (λ,θ, i, j) is the neighbourhood based contrast masking, The neighbourhood consists of the coefficients in the same sub-bands that lie within a window centered at the location *(i, j)*, $N_{i,j}$ denotes the number of coefficients in that neighbourhood, ϑ (λ,θ, i, j) is the DWT coefficient value at location (λ,θ, i, j), and ς is a constant that controls the influence of the amplitude of each neighbouring coefficient. For the LL sub-band, contrast masking is suppressed by setting ε = 0. For other sub-bands, it is set to 0.6. Equation 6 performs the contrast masking. Just Noticeable Distortion (JND) threshold is formulated as specified in [14]:

$$JND_{\lambda,\theta}(r) = \frac{1}{A_{\lambda,\theta}} a.10^{k\left\{log_{10}\left(g_{\theta}f_0 2^{\lambda}/r\right)\right\}^2} \tag{12}$$

Where a, g_θ, k, f_0 are constants, for the amplitude of the DWT 9/7 basis function corresponding to level λ and orientation θ, and r is the visual resolution of the display in pixels/degree. The values given in Tables 1 and 2 are used for the above mentioned constants.

Table 1. Basic function amplitude A(λ, θ) for 1st level for a 9/7 DWT [14].

Orientation	DWT 1st Level Decomposition
LL	0.62171
LH, HL	0.67234

Table 2. Parameters for DWT threshold model [14].

a	k	fo	gLL	gHL, gLH	gHH
0.495	0.466	0.401	1.501	1.0	0.534

An initial random population p is created by setting the parameter values as shown in Table 3. If b is the individual of this population and X is the image then for each individual in the population, following steps are performed by GP to determine a GP expression for optimal strength of the embedded watermark. The algorithm is as follows:

- *Step1*: *Convert the image X into 1st level 2D-DWT.*
- *Step2*: *If the LH or HL sub-band and then perform the following actions*:
  1. *Compute blocks each of size m×m.*
  2. *Compute sum of square of each coefficient in the m×m block using Equation 1.*
  3. *Sort blocks in descending order and select top b blocks embedding.*
  4. *Compute perceptual mask using Equation 4.*
  5. *Embed the watermark using Equation 2.*
  6. *Compute fitness using equation Fitness=Structure Similarity Index Measure (SSIM).*
  7. *Perform step2 for different block sizes 4, 8, 16, 32 to train the GP.*

There are two stopping criteria for the algorithm. One condition is that when the specified number of iteration is reached and the second is when the desired fitness value is achieved.

4. Simulation Details

Matrix Laboratory (MATLAB) is used for the implementation of the system with GP and GPLAB toolboxes. Standard images such as baboon, Lena, cameramen, airplane, Barbara of size 512×512 are used as cover images. Ramped half and half method defined in GPLAB is used to create initial population in GP. GP functions used include sin, cos, my log, my divide, ×, -, and + to perform operation on variables and constants. Variable terminals include luminance, contrast masking and DWT coefficients. Random constants are used as constant terminals. When generations reach to the specified maximum number of generations or when program reaches the threshold fitness level, it terminates. The fitness of individual is set to SSIM. Watson perceptual models JPEG 2000, values for the first level are used for embedding purpose. Watermark embedding and watermark detection are performed on the images. All images used are gray scale of size 512×512. Watermarks are generated randomly and consist of real number. Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) are used to calculate and evaluate the quality of the watermarked and distorted image.

Table 3. GP control parameters.

Objectives	GP parameters settings
Function Set	+,—,×,mydivide,mylog,sin,cos
Terminal Set	Constant: random constants in range [-1 1] Variables: ($a_l(\lambda,\theta, i, j)$, $a_c(\lambda,\theta, i, j)$),coef
Fitness	SSIM
Selection	Generational
Population Size	300
Initial Max Depth	6
Initial Population	Ramped half and half
Operator Prob Type	Variable
Sampling	Tournament
Expected No of off Springs	Rank89
Survival Mechanism	Keep best
Real Max Level	28
Termination	Generation 30

Attacks are performed in the MATLAB environment. We demonstrate the performance of the proposed scheme in term of robustness and imperceptibility. Figure 3 represent the PSNR and MSE values of the watermarked images with different block sizes of 4, 8, 16 and 32. It can be seen that PSNR value of all images, using different block sizes lies, well above 55 and for Barbara and airplane it reaches more than 60. It proves that our technique is equivalently good irrespective of the size of block chosen for embedding watermark. When we compare the value of PSNR of cameraman and baboon, we see a comparatively high PSNR value for the baboon, for all block sizes. This is due to the high texture of the baboon image. We have used texture feature to imperceptibly embed the watermark [5].

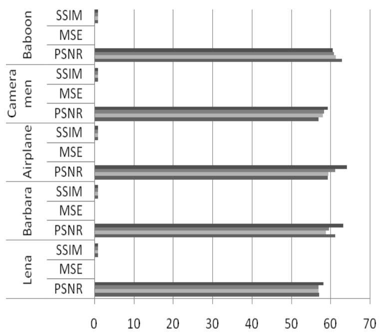

Figure 3. Comparison of imperceptibility of the proposed multi-block technique on different images with different block sizes.

Some common image processing operations such as filtering, compression, noise addition, rotation, cascading attacks are also applied to test the robustness of the proposed technique. Figures 4 to 7 represent robustness level of the proposed technique against different types of attacks. Higher value of PSNR reflects the improved imperceptibility level of the watermarked image.

Table 4 compares the results of the proposed technique with the ones proposed in [1, 10], labelled as Technique A and Technique B respectively, in terms of the quality of watermarked image, i.e., PSNR, MSE, and SSIM. The values in the column labelled "Proposed" in Table 4 show that our multi-block watermarking technique gives significantly better results than other two techniques. Figure 3 represents the comparison of PSNR, MSE, and SSIM values of different images using block size of 4, 8, 16, 32.

Table 4. Comparison of cascading attack of varying strength, on image using different block sizes.

Type of attack	Attack value	PSNR			MSE		
		Technique A [10]	Technique B[1]	(Proposed)	Technique A [10]	Technique B[1]	(proposed)
low pass filter	2×2	21.86	37.18	39.61	81.47	12.44	7.12
	3×3	24.01	44.49	45.59	49.37	2.311	1.80
	4×4	20.41	37.18	39.61	112.37	12.44	7.11
	5×5	20.30	44.47	45.56	114.65	2.32	1.82
	6×6	18.65	37.18	39.61	166.67	12.45	7.11
G.noise	500	14.19	31.39	35.54	499	47.19	7.51
	1000	11.32	30.75	34.89	1002	54.76	3.42
	5000	05.46	29.68	32.62	5014	70.03	8.55
	10000	03.54	29.37	31.68	10014	75.23	6.85
	15000	02.64	29.23	31.26	15046	77.72	10.17
Median filter	2×2	21.61	37.10	39.37	86.33	12.68	7.51
	3×3	26.52	39.72	42.80	27.87	6.93	3.41
	4×4	20.84	36.43	38.80	102.45	14.46	8.55
	5×5	22.57	37.46	39.77	68.73	11.68	6.85
	6×6	19.61	35.87	38.06	135.44	16.81	10.17
Weiner jpeg & G.Noise	75,500	20.76	31.35	35.50	109.01	47.60	18.38
	50, 1000	18.54	30.73	34.86	185.0	54.98	21.23
	50,5000	12.12	29.67	32.61	842.0	70.19	35.67
	50, 1000	9.56	29.37	31.66	1612	75.17	44.36
	25,5000	12.59	29.65	32.59	752.0	70.47	35.84
	25,9000	10.08	29.40	31.79	1402	74.66	43.05
JPEG	100%	40.59	48.22	61.83	1.100	0.98	0.04
	75%	29.22	40.29	43.66	15.08	6.08	2.80
	50%	27.26	38.87	41.65	23.65	8.44	4.44
	25%	25.32	37.46	39.95	36.95	11.68	6.58
	10%	22.39	35.43	38.00	72.62	18.62	10.30

4.1. Filtering Attack

The watermarked image is attacked with a low pass filter, median filter with a window sizes from 2×2 to 6×6, and the Wiener filter. The watermark is detected after each attack which shows our technique is robust to these types of attack as shown in Figures 4 and 5.

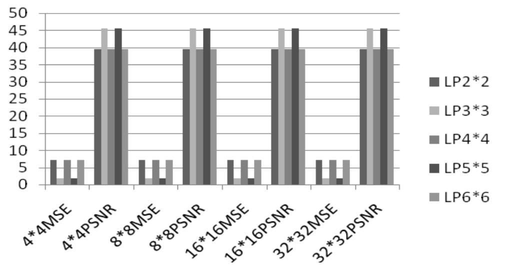

Figure 4. Comparison of PSNR and MSE values for the low pass filter attack on image using different block sizes.

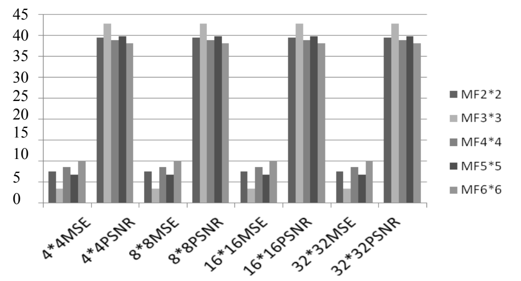

Figure 5. PSNR and MSE values for the median filtering attack of varying strength on images using different block sizes.

4.2. Noise Attack

The other type of attack carried out is Gaussian noise of window size 3×3 with standard deviation of 0.2. In addition, noise with power of 0.5k, 1k, 5k, 10k and 15k is added and the original watermark is detected from the attacked images (where k is 1000). The noise attack results are shown in Figure 6.

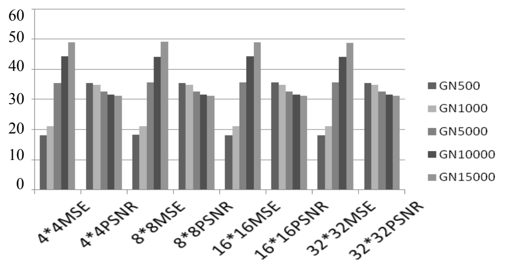

Figure 6. Comparison of adding Gaussian noise with different variance, such as 0.5k, 1k, 5k, 10k, 15k on image using different block sizes.

4.3. Compression Attack

Compression of watermarked images is performed with different JPEG quality values. In our experiment with Quality Factor (QF) as low as 5%, is applied and the watermark can still be detected by the detector.

4.4. Cascading Attacks

The image is also tested against cascading attacks. First, the image is subjected to Weiner filtering, then the resultant image is compressed with different JPEG QFs such as 75%, 50%, 25%. We then add Gaussian noise with different variance such as 0.5 k, 1 k, 5 k, 10 k in corrupt image. The detector was able to detect the watermark after each attack. The result of cascading attacks is shown in Figure 7.

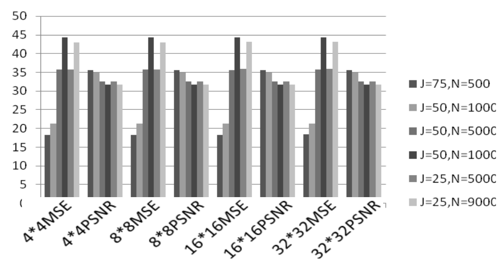

Figure 7. Comparison of JPEG attack of varying quality factors, together with Gaussian noise attack with different variance on images using different block sizes.

4.5. Geometric Attacks

In order to, show the robustness against geometric attacks, cropping is used. Cropping with different rates (75%, 50%, and 15%) is applied. The watermark is also found to be robust against cropping attack. Watermark is also tested against the resize attack. A 512×512 image is resized to ½ and ¾ of its original size. We were still able to detect the watermark. It indicates that our technique is robust against the resize attack.

We also tested rotation attack of degree +45 and -45 degree. After performing rotation attack, the watermarked image is submitted to the watermark detector which successfully detected the watermark.

5. Conclusions

In this paper we have proposed a multi-block watermarking technique. The proposed technique uses GP to generate perceptual mask of gray scale images in DWT domain. The novelty of the proposed technique is that it can embed watermark using any block size of an image.

The proposed technique intelligently offers a trade-off between robustness and perceptual changes that occur due to different set of malevolent attacks. Luminance sensitivity, self and neighbourhood contrast masking of each coefficient are calculated and used to generate perceptual mask that is later used to determine optimal level of watermark for each of the selected coefficient in the block. The coefficients in which watermark is embedded are scattered throughout the image which makes it robust to different manipulations such as filtering attack, JPEG compression, adding noise, geometric and cascading attack etc., We have compared our multi block based technique with single block size technique presented in [1] and the genetic perceptual model based technique proposed in [10]. We have compared PSNR value of attacked images and reults show that our technique is 68% robust, while [1, 10] are only 45% and 63% robust respectivelly. Experimental results indicate significant improvement in the imperceptibility of watermark for different block sizes and also considerable enhancement in the robustness under different attacks.

Acknowledgements

This work is supported by Bright Spark scholarship, University of Malaya, Malaysia.

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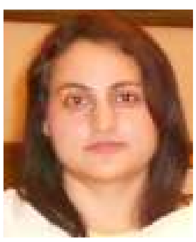

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