Adaptive Digital Image Watermarking Based on Combination of HVS Models

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Abstract. *In this paper two new blind adaptive digital watermarking methods of color images are presented. The adaptability is based on perceptual watermarking which exploits Human Visual System (HVS) models. The first method performs watermark embedding in transform domain of DCT and the second method is based on DWT. Watermark is embedded into transform domain of a chosen color image component in a selected color space. Both methods use a combination of HVS models to select perceptually significant transform coefficients and at the same time to determine the bounds of modification of selected coefficients. The final HVS model consists of three parts. The first part is the HVS model in DCT (DWT) domain. The second part is the HVS model based on Region of Interest and finally the third part is the HVS model based on Noise Visibility Function. Watermark has a form of a real number sequence with normal distribution.*

Keywords

Digital image watermarking, Human Visual System models, Discrete Cosine Transform, Discrete Wavelet Transform, Noise Visibility Function, color spaces, watermark embedding, watermark detection.

1. Introduction

Over the past ten years there has been a massive spreading of digital multimedia, broadband networks and new developments in digital technology. Multimedia content is not longer limited to a physical carrier such as CD, DVD or new Blue-ray discs but it can be transmitted over broadband networks and reach various places on Earth. This fact together with the availability of powerful tools for editing, lossless copying and transmission of digital multimedia have made ownership protection and authentication of digital multimedia a very important issue that needs to be solved. One possible solution of this serious problem is digital watermarking defined as a technique of embedding additional information into digital multimedia while preserving perceptual quality of watermarked data [3]. The additional information that is embedded is called watermark and it can have a form of a symbol or number sequence, pictures, speech segment or even one bit information. Watermarks can be detected or extracted form tested data according to the used method. Digital watermarking has several applications that use watermarks with various properties. According to that, watermarks can be divided into visible watermarks, invisible watermarks, fingerprinting watermarks, bit-stream watermarks, fragile watermarks, semi-fragile watermarks, and dual watermarks. Digital watermarking can be used for ownership protection, fingerprinting, copy control or protection, broadcast monitoring, transmission of control and support information and integrity verification of digital multimedia. All these applications use watermarks with different requirements. There are three basic requirements on digital watermarks: robustness, perceptual transparency and capacity. These requirements are in conflict which each other. If the embedded watermark shall be robust against attacks energy of embedded watermark has to be increased but on the other hand a problem with perceptual transparency requirement arises. Vice versa if perceptual transparency of embedded watermark is vital we have to decrease the watermark energy but at the same time a problem of watermark robustness arises. There are applications as integrity verification where fulfilling of all three requirements at the same time is not required. On the other hand, ownership protection requires robustness and at the same time perceptual transparency requirement fulfilling. This is the reason why proper selection of original signal components or coefficients for watermark embedding and the allowed amount of modification of these signal components in watermark embedding process are a very critical issue. HVS models provide an elegant solution of this problem in case of digital image watermarking [1]. This paper presents two image adaptive methods of invisible watermarking in transform domain for still color images. These methods do not require the presence of original data in watermark detection process. It is the continuation of [2] that describes adaptive watermark embedding into grayscale images as the algorithms of coefficients selection, their modifications in watermark embedding process and watermark detection process presented in this paper are the same as in [2]. Watermark embedding itself is performed in DCT and DWT transform domain of color components by using of RGB and YCrCb color spaces. Watermarks embedded into particular color components were tested on robustness against various types of attacks.

2. Perceptual Digital Image Watermarking

Perceptual digital image watermarking methods use knowledge of human visual system to fulfill conflicting requirements on digital watermarks. In this paper we present two methods of perceptual watermarking for still color images where HVS models are used to select perceptually significant image components for watermark embedding and at the same time to scale the watermark before embedding into original data. The first method operates in DCT domain and is denoted as M_DCTc. The second method denoted M_DWTc is based on DWT.

2.1 Watermark Embedding Process

According to the used color space, color still images can be described using three color components. From a mathematical point of view color still images can be represented by a tensor of size N_1xN_2x3 where N_1xN_2 is the image size. By using of 24 bits color coding each color component is described by 8 bits per pixel which means that color components of color images can be seen as grayscale still images. According to these considerations perceptual watermarking methods designed for grayscale images in [2] can be applied also for color still images.

Watermark embedding in case of color still images by using methods M_DCTc and M_DWTc can be described by the following nine steps (Fig. 1):

- color image conversion to a required color space,
- selection of one color component,
- transformation of the selected color component,
- construction of HVS model,
- watermark generation,
- coefficients selection,
- watermark embedding,
- inverse transformation,
- conversion of the watermarked color image to the required color space.

The only condition for color image conversion to the required color space is the linear dependency between the original (RGB) color space and the required color space. This condition has the origin in HVS model computation in various color spaces and it will be described in the next section. The conversion of the watermarked image to the required color space is performed only for watermark embedding algorithms in case that the required color space of the watermarked image is different than the color space of the watermark embedding algorithm.

2.1.1 Transformation of a Selected Color Component

Method M_DCTc uses 2D DCT with block size $M\times M$ which is applied on a selected color image component I^{Φ} and the results are DCT transform coefficients $I^{\Phi}_{DCT}(u, v, k)$ where Φ is the index of the color image component, u,v are spatial coordinates and k is the index of a block. Method M_DWTc uses L_D levels 2D DWT based on 9/7 biorthogonal wavelets. The result of this transformation are DWT coefficients $I^{\Phi}_{DWT}(L, \Omega, m, n)$ where L is the decomposition level and Ω denotes orientation (1, 2, 3, 4 for approximation, horizontal, diagonal and vertical details).

2.1.2 Construction of HVS Model

For the presented methods of perceptual image watermarking we have developed algorithms of combining HVS models in DCT or DWT domain with two different HVS models to get a better model of human's eye properties and at the same time to achieve better fulfilling of conflicting requirements on digital watermarks.

2.1.2.1 HVS Model in DCT Domain for Color Images

The first step in HVS model construction in DCT space is the computation of frequency sensitivity Just Noticeable Difference (JND) thresholds $T_\Phi(u, v)$ for YOZ color space according to the following equation

$$\log T_\phi(u,v) = \begin{cases} \log\left(\dfrac{T_{\min\phi}(f_{u,0}^2 + f_{0,v}^2)^2}{(f_{u,0}^2 + f_{0,v}^2)^2 - 4(1-r_\phi) f_{u,0}^2 f_{0,v}^2}\right) & if\ f_{u,v} \le f_{\min\phi} \\ \log\left(\dfrac{T_{\min\phi}(f_{u,0}^2 + f_{0,v}^2)^2}{(f_{u,0}^2 + f_{0,v}^2)^2 - 4(1-r_\phi) f_{u,0}^2 f_{0,v}^2}\right) + & if\ f_{u,v} > f_{\min\phi} \\ +S_\phi(\log\sqrt{f_{u,0}^2 + f_{0,v}^2} - \log f_{\min\phi})^2 & \end{cases} \quad (1)$$

where $f_{u,0}$, $f_{0,v}$ are horizontal and vertical spatial frequency, respectively, $T_{\min\Phi}$ is the minimum threshold occurs at spatial frequency $f_{\min\Phi}$, S_Φ determines the steepness of the parabola, and r_Φ is the model's parameter.

The JND thresholds in YOZ color space can be converted to other color spaces. The only condition is the linear dependency between YOZ color space and the required color space. If ${}_{DEF}M_{YOZ}$ is the conversion matrix from color space DEF to color space YOZ then the conversion of JND thresholds from YOZ color space to the required DEF color space can be expressed by the following equations

$$T_D(u,v) = \frac{1}{C(u)C(v)} \min\left\{\frac{T_Y(u,v)}{|M_{1,1}|}, \frac{T_O(u,v)}{|M_{2,1}|}, \frac{T_Z(u,v)}{|M_{3,1}|}\right\}, \quad (2)$$

$$T_E(u,v) = \frac{1}{C(u)C(v)} \min\left\{\frac{T_Y(u,v)}{|M_{1,2}|}, \frac{T_O(u,v)}{|M_{2,2}|}, \frac{T_Z(u,v)}{|M_{3,2}|}\right\}, \quad (3)$$

$$T_F(u,v) = \frac{1}{C(u)C(v)} \min\left\{\frac{T_Y(u,v)}{|M_{1,3}|}, \frac{T_O(u,v)}{|M_{2,3}|}, \frac{T_Z(u,v)}{|M_{3,3}|}\right\} \quad (4)$$

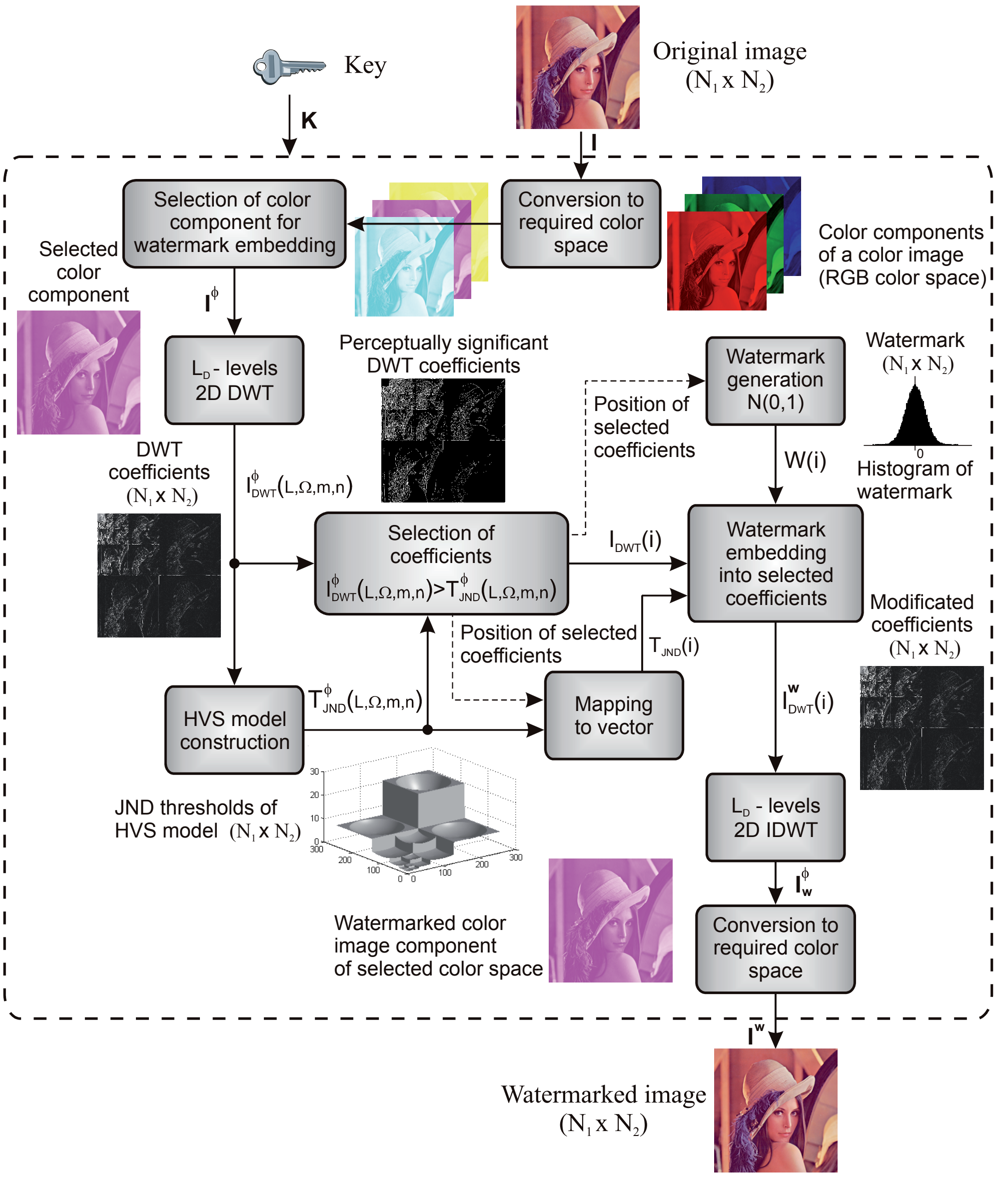

Fig. 1. Watermark embedding principle (M_DWTc case)

where $C(u)$, $C(v)$ are DCT normalization constants and $M_{i,j}$ are elements of conversion matrix $_{DEF}M_{YOZ}$. Examples of DEF color spaces are RGB, YC_rC_b, YUV, YIQ and XYZ [4].

In the next step the thresholds of frequency sensitivity for various color components of different color spaces are weighted by HVS model based on Region of Interest (ROI) according to the equation

$$T_{\phi}^{f}(u,v,k)=T_{\phi}(u,v).\left(1+\frac{\beta.T_{ROI}(\vartheta,f,x_k)}{100.\max(T_{ROI})}\right) \tag{5}$$

where $x_k = x$ from block k: $\min(\|x - x_{ROI}\|)$, x_{ROI} is the center point of ROI, β [%] controls the impact of HVS model based on ROI on the final HVS model and $T_{ROI}(\vartheta, f, x_k)$ are thresholds of HVS model based on ROI that expresses the non-uniform density of photoreceptors on a human's eye retina. They can be computed as a function of eccentricity $e(\vartheta, x)$ according to the equation

$$T_{ROI}(\vartheta,f,x)=\begin{cases}\exp(0{,}0461.f.e(\vartheta,x)) & for \quad f\le f_m(x)\\ \exp(0{,}0461.f_m(x_{\max}).e(\vartheta,x_{\max})) & for \quad f> f_m(x)\end{cases} \tag{6}$$

where x is the pixel position in an image, x_{max} denotes the pixel position where T_{ROI} reaches its maximum and after that point remains constant, $f_m(x)$ is the cutoff frequency and ϑ is the viewing distance measured in image heights [7].

JND thresholds of weighted frequency sensitivity in each color image component are further corrected by luminance sensitivity using the equation [8]

$$T_{\phi}^{l}(u,v,k)=T_{\phi}^{f}(u,v,k).\left(\frac{I_{DCT}^{Y}(0,0,k)}{\overline{Y}_{0,0}}\right)^{a_T} \tag{7}$$

where $I_{DCT_Y}(0,0,k)$ is the DC coefficient for block k in luminance component computed from RGB color space by the following equation

$$Y = 0,299R + 0,587G + 0,114B\,. \tag{8}$$

Thresholds of the final HVS model used in the presented watermarking methods are got by the correction of luminance sensitivity by neighborhood masking according to the equation [5]

$$T_\phi^c(u,v,k) = T_\phi^l(u,v,k).\max\left[1,\left(e^{\frac{-\pi\left((u-u_m)^2+(v-v_m)^2\right)}{\left(\varphi.\max\left(1,\sqrt{u^2+v^2}\right)\right)^2}}\frac{\left|I_{DCT}^\phi(u_m,v_m,k)\right|}{T_\phi^l(u,v,k)}\right)^{w_{u,v}^\phi(k)}\right] \tag{9}$$

where parameter that controls the masking effect $w^{\Phi}_{u,v}(k)$ for color image component Φ is evaluated as

$$w_{u,v}^\phi(k) = \begin{cases} \dfrac{\lambda}{3M^2}\displaystyle\sum_{u=1}^{M}\sum_{v=1}^{M}\left(1-NVF^\phi(u,v,k)\right) & if \displaystyle\sum_{u=1}^{M}\sum_{v=1}^{M}NVF_P^\phi(u,v,k) < M^2 \\ \dfrac{\lambda}{M^2}\displaystyle\sum_{u=1}^{M}\sum_{v=1}^{M}\left(1-NVF^\phi(u,v,k)\right) & if \displaystyle\sum_{u=1}^{M}\sum_{v=1}^{M}NVF_P^\phi(u,v,k) = M^2 \end{cases} \tag{10}$$

where $NVF^{\Phi}(u, v, k)$ are the values of Noise Visibility Function (NVF) in block k for color component Φ, $NVF^{\Phi}_P(u, v, k)$ is the thresholded NVF which detects sharp edges in an image and λ determines the maximal value of this parameter according to the robustness requirements on embedded watermark. Noise Visibility Function describes noise visibility in an image and is given as

$$NVF(m,n) = \frac{1}{1+\mu\sigma_x^2(m,n)} \tag{11}$$

where σ_x^2 denotes the local variance of the image in a window centered on the pixel with coordinates (m,n), and μ is a tuning parameter corresponding to the particular image [6].

2.1.2.2 HVS Model in DWT Domain for Color Images

Detection thresholds of frequency sensitivity $T^{\Phi}_{L,O}$ in various subbands and on various levels of decomposition for 9/7 biorthogonal wavelets in YCrCb color space were determined by psychological experiments and they can be expressed by the following equation

$$T_{L,\Omega}^\phi = \frac{T_{\min}^\phi}{A_{L,\Omega}}10^{S^\phi\left(\log\frac{f_L}{f_0^\phi g_\Omega^\phi}\right)^2} \tag{12}$$

where Φ denotes the color image component $A_{L,\Omega}$ are the basis function amplitudes, $T^{\Phi}_{\min}$ is the minimum threshold occurs at spatial frequency $f_0^{\Phi} g_\Omega^{\Phi}$, f_L is the spatial frequency of decomposition level L and g_Ω^{Φ} shifts the minimum thresholds by an amount that is a function of orientation [9].

These JND thresholds in YCrCb color space can be converted to other color spaces using similar equations as (2), (3) and (4). The only condition is the linear dependency between YCrCb color space and the required color space DEF by considering conversion matrix $_{DEF}M_{YOZ}$.

Weighting of frequency sensitivity thresholds by using HVS model based on ROI is given by the equation

$$T_\phi^f(L,\Omega,m,n) = T_{L,\Omega}^\phi\cdot\left(1+\frac{\beta.T_{ROI}^{L,\Omega}(m,n)}{100.\max\left(T_{ROI}^{L,\Omega}\right)}\right). \tag{13}$$

To incorporate luminance sensitivity to HVS model for color images, the following equation was designed

$$T_\phi^l(L,\Omega,m,n) = T_\phi^f(L,\Omega,m,m).\left(\frac{I_{DWT}^Y(L,1,m,n)}{\overline{I}_{DWT}^Y(L,1,m,n)}\right)^{a_T} \tag{14}$$

where $I_{DWT}^Y(L,1,m,n)$ is the DWT coefficient in approximation on decomposition level L of luminance component of color image that is computed by (8) and $\overline{I}_{DWT}^Y(L,1,m,n)$ is the DWT coefficient of a homogenous image with mean luminance in approximation on decomposition level L.

JND thresholds of neighborhood masking for each DWT coefficient can be evaluated as

$$T_\phi^c(L,\Omega,m,n) = T_\phi^l(L,\Omega,m,n).\max\left[1,\left(\varphi(m_M,n_M).\frac{\left|I_{DWT}^\phi(L,\Omega,m_M,n_M)\right|}{T_\phi^l(L,\Omega,m,n)}\right)^{w_{L,\Omega,m,n}^\phi}\right] \tag{15}$$

where $I_{DWT}^\phi(L,\Omega,m_M,n_M)$ and $I_{DWT}^\phi(L,\Omega,m,n)$ are DWT coefficients in color component ϕ and parameter of masking effect control is given by

$$w_{L,\Omega,m,n}^\phi = \begin{cases} \dfrac{\lambda}{3\cdot 2^{L-1}}\left(1-NVF^\phi(L,\Omega,m,n)\right) & if\ NVF^Y(L,1,m,n) < P_1 \\ \dfrac{\lambda}{2^{L-1}}\left(1-NVF^\phi(L,\Omega,m,n)\right) & if\ NVF^Y(L,1,m,n) \ge P_1 \end{cases} \tag{16}$$

where $NVF^\phi(L,\Omega,m,n)$ is NVF evaluated in L,Ω subband for color image component ϕ, $NVF^Y(L,\Omega,m,n)$ is NVF for L,Ω subband of luminance component and the rest of parameters have similar meaning as in section 2.1.2.1.

2.1.3 Watermark Generation

Watermark is generated by using of a Pseudo Random Number Generator (PRNG) initialized by the secret key K. It has a form of real number sequence with normal distribution, zero mean and unit variance. Its elements are formed in an array $W(m,n)$ with the size of the original image.

2.1.4 Coefficients Selection

Perceptually unimportant components such as very small high frequency components are suppressed by lossy image compression and other low-pass operations therefore we perform watermark embedding only into perceptually significant coefficients. Vector $I_{DCT}(i)$ of selected AC coefficients in case of M_DCTc method expresses the following equation

$$I_{DCT}(i) = I^{\phi}_{DCT}(u,v,k) \ \mathit{if} \ I^{\phi}_{DCT}(u,v,k) > T^{\phi}_{JND}(u,v,k) \quad (17)$$

where $u,v \in$ zigzag sequence and $T_{JND}(u,v,k)$ are JND thresholds of HVS model for color component Φ. Perceptually significant DWT coefficients in M_DWTc method are selected form detail subbands on each decomposition level according to the equation

$$I_{DWT}(i) = I^{\phi}_{DWT}(L,\Omega,m,n) \ \mathit{if} \ I^{\phi}_{DWt}(L,\Omega,m,n) > T^{\phi}_{JND}(L,\Omega,m,n) \quad (18)$$

where $T^{\Phi}_{DWT}(L,\Omega,m,n)$ are thresholds of HVS model and $I_{DWT}(i)$ is the vector of selected coefficients. The position of the selected coefficients is used to select corresponding JND thresholds of HVS model and watermark elements which are mapped to vectors $T_{JND}(i)$ and $W(i)$ respectively.

2.1.5 Watermark Embedding

Watermark embedding into selected coefficients itself is the same as in [2]. Watermark embedding into the selected transform coefficients is described by the following equation

$$I^{W}_{DOT}(i) = \begin{cases} I_{DOT}(i) + sign\left(WT(i)\right) \cdot \left(W(i) \left\lfloor \dfrac{T_{JND}(i)}{W(i)} \right\rfloor \right) & \mathit{if} \quad Mask(i) = 0 \wedge WT(i) > T_{JND}(i) \\ I_{DOT}(i) + sign\left(WT(i)\right) \cdot \left(W(i) \left\lfloor \dfrac{2T_{JND}(i)}{W(i)} \right\rfloor \right) & \mathit{if} \quad Mask(i) = 1 \wedge WT(i) > 2T_{JND}(i) \\ I_{DOT}(i) + W(i) T_{JND}(i) & \mathit{otherwise} \end{cases} \quad (19)$$

where $I_{DOT}(i)$ and $I^{W}_{DOT}(i)$ are DCT (DWT) coefficients of the original and watermarked color image component, respectively, $sign(x)$ is the sign function, $\lfloor \ \rfloor$ is rounding towards zero, $WT(i) = W(i).T_{JND}(i)$ and $Mask(i)$ are elements of $Mask(m,n)$ corresponding to the selected coefficients. $Mask(m,n)$ performs segmentation of the original image or each subband in the case of M_DWTc method to three regions with different amount of allowed modification according to the following equation

$$Mask(m,n) = \begin{cases} 0 & \mathit{region\ inside\ of\ ROI\ without\ tetxures} \\ 1 & \mathit{region\ inside\ of\ ROI\ with\ textures} \\ 2 & \mathit{region\ outside\ of\ ROI} \end{cases} \quad (20)$$

Segmentation to inside and outside regions of ROI is done by T_{ROI} model thresholding and detection of textures is performed by local variance computation.

2.1.5.1 Inverse Transformation

Modified and unmodified transform coefficients are transformed back to pixel domain by using of block 2D IDCT or L_D levels 2D IDWT. Finally the watermarked color image component together with two other color components give the watermarked color image I^W.

2.1.6 Watermark Detection Process

Watermark detection is performed without the presence of the original image. Watermark detection in a color test image I^T is expressed by the following steps:

- color image conversion to the color space of the watermark embedding process,
- selection of the watermarked color component,
- transformation of the selected color component,,
- construction of HVS model,
- watermark generation,
- coefficients selection,
- watermark detection and decision.

The first three steps use similar algorithms as in the watermark embedding process but the specific color space and the selected color image component are part of a secret key. HVS model used in the watermark detection algorithm uses only frequency sensitivity that is weighted by HVS model based on ROI (5)(13). Watermark detection is based on correlation computation between the selected perceptually significant transform coefficients and the watermark scaled by visibility thresholds of HVS model according to the equation

$$KT = \frac{1}{V_D} \sum_{i=1}^{V_D} I^{T}_{DOT}(i) T_{JND}(i) W(i) \quad (21)$$

where $I^{T}_{DOT}(i)$ are the transform coefficients of the test color image component, $T_{JND}(i)$ are the thresholds of HVS model, $W(i)$ are the elements of watermark, and V_D is the number of selected significant transform coefficients. The decision about watermark presence in the test image is made according to the comparison between the computed correlation and a selected threshold.

3. Experimental Results

Verification of the proposed methods has been performed on the color image "Lena" (256x256x24b). The proposed methods of watermark embedding into color still images were tested on watermarked image quality and watermark robustness against attacks by watermark embedding into color image components of RGB and YCrCb color spaces. The results are shown in Tab. 1, Tab. 2, Tab. 3 and Tab. 4. After each attack the detection of 500 different watermarks from which only one was really used for embedding process was evaluated. Among all detected watermarks only one should have given the largest correlation output.

The experimental results showed that watermark embedding into color images by using M_DCTc method in YCrCb color space provides the best image quality by watermark embedding into Cr color component but at the same time the watermark embedded into this color component was destroyed by almost all tested attacks (Tab. 1). Embedded watermark was most robust in Y color image component and the watermarked image was without any visible distortion. Watermark embedded into Cb color component was not robust against lossy image compressions.

Attack	Para-meters	Y		Cr		Cb	
		PSNR [dB]	KT	PSNR [dB]	KT	PSNR [dB]	KT
no attack	-	41,493	78,901	51,381	190,81	49,036	836,40
JPEG	Q = 70	31,688	75,931	32,133	N	32,139	N
	Q = 30	29,292	100,08	29,509	N	29,507	N
JPEG 2000	1.0 bpp	32,385	38,390	32,736	N	32,734	N
	0.5 bpp	29,438	N	29,513	N	29,472	N
Filtration	W 3x3	35,033	36,311	35,314	N	35,258	701,70
	M 3x3	32,009	21,920	32,188	144,27	32,175	544,13
Gaussian noise	0.001	29,738	53,294	29,996	N	29,972	644,26
	0.005	23,077	24,250	23,128	N	23,123	259,14
Brightness change	+30	18,694	77,445	18,715	N	18,710	814,41
	-30	18,647	69,763	18,663	N	18,664	805,06
Contrast change	0.1	19,701	76,118	20,008	N	19,997	568,38
	0.5	20,776	77,202	21,089	N	21,077	588,12
Gamma correction	0.5	14,128	82,192	14,132	N	14,130	962,67
	1.5	18,183	70,028	18,197	N	18,199	556,11
Resize	1/2	30,922	N	30,986	N	30,967	652,06
	3/2	39,173	62,864	41,058	184,22	40,813	799,20
Cropping	1/4	10,884	79,727	10,887	N	10,887	938,32
	1/2	7,497	88,100	7,498	N	7,498	841,93
Rotation	0.5°	26,202	27,268	26,290	N	26,283	561,96
	1.0°	21,973	N	22,007	N	22,004	N

Tab. 1. Watermark robustness by using M_DCTc method in YCrCb color space. N – detection failed.

Attack	Para-meters	R		G		B	
		PSNR [dB]	KT	PSNR [dB]	KT	PSNR [dB]	KT
no attack	-	42,430	1092,8	44,677	138,70	44,032	10085
JPEG	Q = 70	32,036	N	31,906	83,76	32,121	N
	Q = 30	29,449	N	29,392	93,62	29,501	N
JPEG 2000	1.0 bpp	32,556	N	32,557	45,81	32,695	N
	0.5 bpp	29,458	N	29,426	N	29,483	N
Filtration	W 3x3	34,978	700,68	35,170	72,50	34,978	9657,1
	M 3x3	32,008	584,69	32,114	42,72	32,068	7384,5
Gaussian noise	0.001	29,787	940,51	29,891	87,29	29,863	9628,9
	0.005	23,085	536,22	23,110	35,14	23,102	8866,5
Brightness change	+30	18,700	1017,9	18,704	138,48	18,702	10081
	-30	18,648	1092,8	18,661	111,61	18,654	10066
Contrast change	0.1	19,870	730,33	19,909	115,13	19,962	N
	0.5	20,926	803,56	20,987	115,48	21,020	N
Gamma correction	0.5	14,129	1057,3	14,129	153,01	14,130	11467
	1.5	18,182	933,67	18,194	114,85	18,192	9218,8
Resize	1/2	30,873	553,42	30,960	37,64	30,890	8611,0
	3/2	39,160	1014,2	40,161	112,95	39,676	9751,6
Cropping	1/4	10,885	1040,2	10,886	138,26	10,885	9911,7
	1/2	7,498	1183,1	7,498	151,33	7,498	12081
Rotation	0.5°	26,207	485,58	26,252	51,71	26,230	7297,5
	1.0°	21,977	N	21,993	N	21,985	N

Tab. 2. Watermark robustness by using M_DCTc method in RGB color space. N – detection failed.

Method M_DCTc in RGB color space provided the best results from the point of watermarked image quality and at the same time from the point of watermark robustness against attacks if watermark was embedded into G color image component (Tab. 2). Watermark embedding into R and B color image components showed low watermark robustness especially against attacks based on image compression algorithms.

In YCrCb color space the M_DWTc method provided the best watermark robustness by watermark embedding into Y color image component where the watermark was successfully detected after all tested attacks except of rotation by 1° (Tab. 3). Watermarks that were embedded into chrominance image components showed low robustness against image compression based on DCT but the image quality expressed by PSNR was better that by watermark embedding into Y color image component although the subjective quality color images with watermark embedded into Y component was very good.

According to the experimental results showed in Tab. 4 the M_DWTc method in RGB color space provided the best watermark robustness and image quality in G color image component but except of JPEG compression and rotation attacks very good results were also obtained by watermark embedding into R and B color image components.

According to the achieved experimental results better results of watermark robustness against the tested attacks in color still images were achieved by using the method based on DWT transformation.

4. Conclusions

In this paper two implementations of HVS models in digital image watermarking were described. The implementation of HVS models in digital image watermarking has one advantage in comparison with their application in compression algorithms. Image compression algorithms such as JPEG use one quantization matrix for the whole image, since the amount of side information in a header of the compressed image data is limited. Watermarking applications have not this limitation and we can take full advantage of HVS models. Experimental results showed that the proper selection of color space and color image component for watermark embedding in connection with HVS model in this specific color space can provide the required watermarked image quality by maximized watermark robustness or the required watermark robustness by maximized watermarked image quality.

Attack	Para-meters	Y		Cr		Cb	
		PSNR [dB]	KT	PSNR [dB]	KT	PSNR [dB]	KT
no attack	-	41,346	110,87	48,029	87,49	46,348	403,34
JPEG	Q = 70	31,720	80,50	32,120	N	32,096	N
	Q = 30	29,324	56,72	29,502	N	29,512	N
JPEG 2000	1.0 bpp	32,189	112,79	32,697	81,04	32,601	420,72
	0.5 bpp	29,329	112,44	29,495	N	29,445	675,37
Filtration	W 3x3	34,928	82,46	35,234	66,92	35,125	373,67
	M 3x3	31,960	57,74	32,144	64,95	32,104	392,40
Gaussian noise	0.001	29,711	84,33	29,966	33,17	29,929	294,96
	0.005	23,068	37,77	23,123	N	23,114	56,08
Brightness change	+30	18,694	110,42	18,712	65,14	18,707	396,53
	-30	18,647	101,52	18,662	76,19	18,660	410,85
Contrast change	0.1	19,782	105,78	20,004	32,95	20,005	109,23
	0.5	20,838	111,06	21,079	37,57	21,077	152,92
Gamma correction	0.5	14,129	112,50	14,131	56,56	14,130	416,23
	1.5	18,182	100,02	18,194	73,13	18,196	348,88
Resize	1/2	30,870	58,84	30,952	68,60	30,908	428,81
	3/2	38,975	94,72	40,628	86,43	40,216	407,75
Cropping	1/4	10,884	92,08	10,886	60,22	10,886	390,98
	1/2	7,498	89,07	7,498	51,77	7,498	349,46
Rotation	0.5°	26,193	46,06	26,274	49,43	26,258	277,10
	1.0°	21,969	N	22,000	N	21,994	201,68

Tab. 3. Watermark robustness by using M_DWTc method in YCrCb color space. N – detection failed.

Attack	Para-meters	R		G		B	
		PSNR [dB]	KT	PSNR [dB]	KT	PSNR [dB]	KT
no attack	-	42,649	940,94	43,122	301,43	41,625	5552,9
JPEG	Q = 70	32,003	352,51	31,843	177,14	31,984	1771,6
	Q = 30	29,455	N	29,372	129,22	29,460	N
JPEG 2000	1.0 bpp	32,464	539,31	32,364	225,76	32,258	3721,1
	0.5 bpp	29,466	436,48	29,400	188,18	29,378	2263,8
Filtration	W 3x3	34,938	795,06	35,003	246,92	34,636	5742,1
	M 3x3	31,992	604,58	32,048	183,80	31,889	5236,1
Gaussian noise	0.001	29,796	889,07	29,822	225,47	29,738	5429,5
	0.005	23,087	474,78	23,094	87,34	23,074	4740,2
Brightness change	+30	18,701	927,42	18,699	300,89	18,692	5552,9
	-30	18,649	940,94	18,658	256,69	18,645	5543,6
Contrast change	0.1	19,931	778,63	19,936	217,04	19,961	2186,1
	0.5	20,985	769,90	21,004	237,03	21,017	2383,9
Gamma correction	0.5	14,130	858,86	14,129	344,65	14,129	6620,5
	1.5	18,183	857,83	18,193	254,27	18,188	4997,1
Resize	1/2	30,858	622,81	30,902	178,75	30,751	5490,9
	3/2	39,223	880,24	39,582	280,73	38,568	5478,8
Cropping	1/4	10,885	618,61	10,885	251,19	10,884	3739,6
	1/2	7,498	563,40	7,498	246,64	7,498	3372,9
Rotation	0.5°	26,205	N	26,232	140,41	26,163	4509,6
	1.0°	21,970	N	21,984	N	21,952	3144,3

Tab. 4. Watermark robustness by using M_DWTc method in RGB color space. N – detection failed.

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