AUTOMATIC FACE REGION WATERMARKING USING QUALIFIED SIGNIFICANT WAVELET TREES

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In this paper, a fully automatic scheme for hiding digital watermarks into face regions is proposed. To achieve this goal, an adaptive two-dimensional Gaussian model of skin color distribution is initially used in order to detect face regions within the initial image. Next each face region is decomposed into three levels with ten subbands, using the Discrete Wavelet Transform (DWT) and three pairs of subbands are formed (HL3, HL2), (LH3, LH2) and (HH3, HH2). Afterwards Qualified Significant Wavelet Trees (QSWTs), which are derived from the Embedded Zerotree Wavelet (EZW) algorithm and they are high-energy coefficient paths, are estimated for a pair of subbands. Finally visually recognizable watermark patterns are redundantly embedded to the coefficients of the highest energy QSWTs and the IDWT is applied to provide the watermarked face area. Performance of the proposed face region watermarking system is tested under various signal distortions such as JPEG lossy compression, sharpening and blurring. Experimental results on real life images indicate the efficiency and robustness of the proposed scheme.

1. Introduction

With image databases and computer networks broadcasting, legal issues of multimedia copyright protection have become very important. To confront this problem digital watermarking has been proposed. Watermarking is a technique for embedding secret data within digital files, which can neither be removed nor decoded by unauthorised users.

Digital watermarking algorithms can generally be grouped into two main categories: those performed in the spatial domain and those in the frequency domain. Early techniques embedded the watermark in the least significant bits (LSBs) of image pixels [1]. However this technique and some other proposed improvements [2], [3] have relative low-bit capacity and are not resistant enough to lossy image compression, cropping and other image processing attacks. On the contrary frequency-domain-based techniques are more robust to attacks. In particular Cox et. al. [4] embedded a set of i.i.d sequences, drawn from a Gaussian distribution, into the perceptually most significant frequency components of an image. In [5] visually recognizable patterns were embedded in images, by selectively modifying the middle frequency of the DCTs of the images. Furthermore several methods [5], [6], [7] used the Discrete Wavelet Transform (DWT) to hide data into the frequency domain. In most of the aforementioned techniques the watermark is a random sequence of bits and can only be detected by employing detection theory. The watermark is retrieved by subtracting the original from the watermarked image and choosing an experimental threshold value to determine when the cross-correlation coefficient denotes a watermarked image. However these techniques are frame-based and thus face regions inside the frame area may not be sufficiently protected. Here it should be stressed that in several applications face regions are addressed as independent video objects and thus it is necessary to be effectively protected.

Modern face detection methods use skin colour characteristics. In [8], face detection is achieved, using a skin colour model based on the chrominance components of the YCrCb colourspace and a suitable face area shape model. The work presented in [9] proposes an adaptive 2D Gaussian model for skin colour distribution, whose parameters are re-estimated based on the current image. Mask area obtained from skin colour detection is processed using morphological tools.

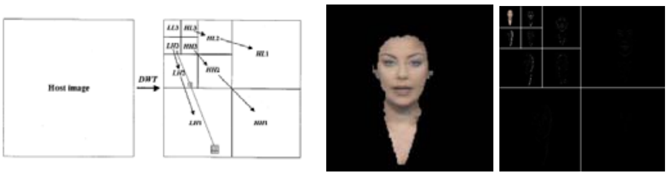
In this paper a fully automatic face-oriented watermarking system is designed and implemented. Our method consists of four main steps: (a) Automatic face detection based on skin color distribution. (b) Discrete Wavelet Transform by which detected face regions are decomposed into three levels, providing ten subbands. (c) Qualified Significant Wavelet Trees (QSWTs) estimation [6] for the pair of subbands with the highest energy content in order to select the coefficients where the watermark should be casted QSWTs, which are based on the definition of the EZW algorithm [10], are high-energy paths of coefficients within the selected pair of subbands and enable adaptive casting of watermark energy in different resolutions, achieving watermark robustness. (d) The watermark pattern is redundantly embedded to both subbands of the selected pair.

Differences between the original and watermarked image are imperceptible to human eyes, while watermarked image are robust under different attacks. The paper is organized as follows. In section 2 the face detection method is shortly described. In section 3 an overview of DWT and QSWT are provided while section 4 presents the embedding and extraction strategies. Finally, experimental results are given in section 5.

2. Face Detection

It was shown in [8] that skin-tone colors are limited to a small area of the Cr-Cb chrominance plane of the YCrCb colourspace. Then all pixels of an image can be checked whether they belong to the skin tone color area or not by using a Bayesian Formula. In the proposed face watermarking scheme, face detection is automatically performed using the algorithm of [9]. According to this algorithm skin-tone colors distribution is approximated using a two-dimensional Gaussian density function. The adapted Gaussian model combined with a minimum risk threshold, estimated using the maximum likelihood criterion on the training set, is applied to the input image (Fig.2a) producing a binary image mask (Fig.2b), which guides the face watermarking procedure.

Afterwards morphological operations (opening and closing) are applied to spatially filter the obtained image masks, while the morphological distance transform and size distribution techniques are used to isolate the disconnected areas and provide separate skin segments. Shape features are also employed to discard skin segments that possess irregular shape. Finally remaining segments are bounded by rectangles and pixel verification is performed within each rectangle according to the adopted algorithm.



(a) (b)

Figure 1. (a) DWT decomposition of a host image, (b) DWT decomposition in face region of image

(a) (b) (c) (d) (e)

Figure 2. (a) Original Image, (b) Face Mask, (c) Watermark, (d) DWT, (e) Image with Watermarked Face Region

3. Qualified Significant Wavelet Trees

By applying the DWT once to an image, four parts of high, middle, and low frequencies (i.e. LL_1, HL_1, LH_1, HH_1) are produced, where subbands HL_1, LH_1 and HH_1 represent the finest scale wavelet coefficients. In the proposed face oriented watermarking scheme, coefficients belonging to the best Qualified Significant Wavelet Trees are chosen as the target coefficients for casting the watermark and the basic definitions are given below.

Firstly a parent-child relationship is defined between wavelet coefficients at different scales, corresponding to the same location. Every coefficient at a given scale can be related to a set of coefficients at the next finer scale of similar orientation. The coefficient at the coarse scale is called the parent, and all coefficients corresponding to the same spatial location at the next finer scale of similar orientation are called children. For a given parent, the set of all coefficients at all finer scales of similar orientation corresponding to the same location are called descendants.

Definition 1: If a wavelet coefficient $x_n(i,j)$ at the coarsest scale satisfy $|x_n(i,j)|>T$, for a given threshold T, then $x_n(i,j)$ is called a significant coefficient *[10]*.

Definition 2: If a wavelet coefficient $x_n(i,j) \in D$ at the coarsest scale is a parent of $x_{n-1}(p,q)$, where D is a subband labeled HL_n, HL_n, HH_n, satisfy $|x_n(i,j)|>T_1$, $|x_{n-1}(p,q)|>T_2$ for given thresholds T_1 and T_2, then $x_n(i,j)$ and its children are called a QSWT.

An example of the DWT and the parent-child relationships is given in Figure 1, where a synthetic and a real image have been decomposed into three levels with ten subbands using the DWT

4. Face Region Watermarking: Embedding and Extraction Strategies

After the unsupervised detection of face regions, each face region is decomposed into three levels with ten subbands, using the DWT and QSWTs are detected for the pair of subbands which contains the highest energy content. Next a visually recognizable watermark image is redundantly embedded in each host face region, by modifying QSWT coefficients. Detailed descriptions of the embedding and extraction strategies are given in the following subsections.

4.1 The Embedding Method

After selecting the pair of subbands containing the highest energy content, QSWTs are detected for this pair and the visually recognizable watermark is cast by modifying the values of the detected QSWTs. Without loss of generality, we assume that pair P_2: (LH_3, LH_2) is selected. Initially the threshold values of each subband are estimated as:

$$T_1 = \frac{1}{N_{P2} * M_{P2}} \sum_{i=1}^{M_{P2}} \sum_{j=1}^{N_{P2}} (\mathrm{x3(i,j)}), \mathrm{x3(i,j)} \in LH_3 \quad (1)$$

$$T_2 = \frac{1}{2N_{P2} * 2M_{P2}} \sum_{p=1}^{2M_{P2}} \sum_{q=1}^{2N_{P2}} (\mathrm{x2(i,j)}), \mathrm{x2(i,j)} \in LH_2 \quad (2)$$

For i=1 to N_{P2} and for j=1 to M_{P2}, where N_{P2} x M_{P2} is the size of LH_3, are founded $\mathrm{x3(i,j)} \geq \mathrm{T1}$ and its children $\{\mathrm{x2}(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}-1) \geq \mathrm{T2}$ and $\mathrm{x2}(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}) \geq \mathrm{T2}$ and $\mathrm{x2}(2\cdot \mathrm{i}, 2\cdot \mathrm{j}-1) \geq \mathrm{T2}$ and $\mathrm{x2}(2\cdot \mathrm{i}, 2\cdot \mathrm{j}) \geq \mathrm{T2}\}$ or $\{[\mathrm{x2}(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}-1) + \mathrm{x2}(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j})$. $+ \mathrm{x2}(2\cdot \mathrm{i}, 2\cdot \mathrm{j}-1) + \mathrm{x2}(2\cdot \mathrm{i}, 2\cdot \mathrm{j})]/4 \geq \mathrm{T2}\}$ These values are stored in QSWT array as $\mathrm{QSWT[t]} = \{\mathrm{x3(i,j)}, \mathrm{x2}(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}-1), \mathrm{x2}(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}), \mathrm{x2}(2\cdot \mathrm{i}, 2\cdot \mathrm{j}-1), \mathrm{x2}(2\cdot \mathrm{i}, 2\cdot \mathrm{j})\}$.

Afterwards summation of the coefficients of QSWT[i] for *i*=0 to *t* is calculated and if the watermark pattern is of size r*x*s then the top r*x*s QSWTs (according to summation) are selected to cast the watermark. For this reason initially the gray levels of the watermark image are sorted in descending order. Then for *i*=1 to r*x*s the watermark pattern is redundantly embedded to subbands LH_3 *and* LH_2 as follows $x'_3(\mathrm{i,j}) = x_3(\mathrm{i,j}) + \alpha \text{ x } w(k,l)$ and $x_2(\mathrm{i,j}) = x_2(\mathrm{i,j}) + \alpha \text{ x } w(k,l)$, where $x_3(i,j) \in LH_3$, w(k,l) is a gray level of the digital watermark, α is a scaling constant and $x_2(\mathrm{i,j}) = \max\{x_2(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}-1), x_2(2\cdot \mathrm{i}-1, 2\cdot \mathrm{j}), x_2(2\cdot \mathrm{i}, 2\cdot \mathrm{j}-1), x_2(2\cdot \mathrm{i}, 2\cdot \mathrm{j})\}$. Finally the IDWT is applied to the modified and unchanged subbands to form the watermarked face region.

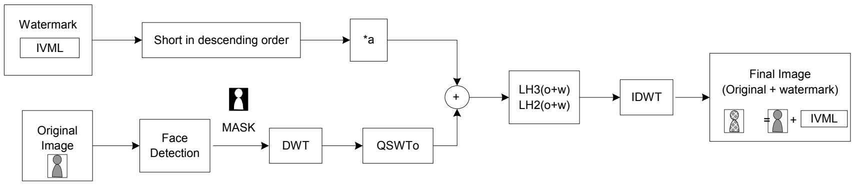


Figure 3: Block diagram of embedding method

4.2 The Extraction Method

The extraction method takes as inputs the original image, the image with the possibly watermarked face region and the scaling constant α to provide the watermark pattern. In particular the following steps are performed:

Step 1: The DWT is estimated for the original and watermarked face regions and the pair of subbands (of original face region) containing the highest energy content is selected.

Step 2: QSWTs are detected for the selected subband pair of the original face region and the best r x s QSWTs are kept. Values of these QSWTs are subtracted from the values of the same QSWTs of the watermarked face region and the result is scaled down by α.

Step 3: The resulting possible watermark coefficients $w_i^3((=(x'^3_i - x^3_i)/a)$ and $w_i^2(=(x'^2_i - x^2_i)/a)$ are averaged and rearranged to provide the visually recognizable watermark image.

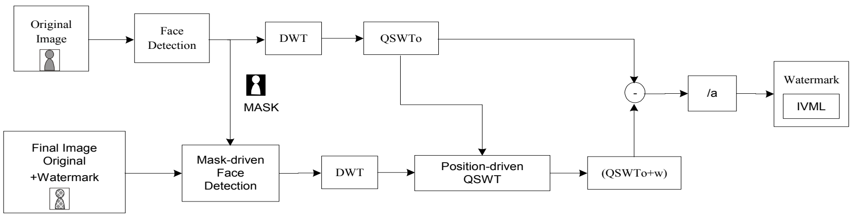


Figure 4: Block diagram of extraction method

5. Experimental Results

The effectiveness and robustness of the proposed automatic face region watermarking system has been extensively tested under various attacks. In the presented experiments a test image of size 300x300 pixels is used, (Figure 2(a)). Afterwards the face detection module is activated providing the face region of Figure 1(b) and the face mask depicted in Figure 2(b). The visually recognizable watermark pattern of our experiments contains the characters "IVML", it is of size 30x10 pixels (Figure 2(c)). According to the size of the watermark image, the top 30x10 QSWTs of the detected face area should be selected for embedding the watermark. After embedding the watermark pattern to the face region, the IDWT is applied to the changed and unchanged subbands to provide the final image with the watermarked face region (Figure 2(e)). As it can be observed the embedded watermark is imperceptible. Different values of the parameter *a* where used for embedding the watermark pattern during our experiments. Table I shows the extraction results from the face region of Figure 2(e) without any attack and using different values of *a*. In this table we observe that as *a* increases better watermark retrieval results are provided on the cost of worst PSNR values. The right value of *a* is application dependent.

Blurring, sharpening, JPEG lossy compression and mixed image processing have been performed to the watermarked face region. Tables II and III show the watermark extraction results for all different cases. As it can be observed, even under low PSNR values the watermark pattern can be extracted and it is still visually recognizable.

Table 1.Extract watermark from face region without attack (Different values of a).

Embedded watermark	IVML			
a	20	50	100	200
PSNR	32.5	29.94	25.51	22.5
Extract watermark	IVML	IVML	IVML	IVML
Correlation	0.967	0.998	0.999	1

Table 2.Extract Watermark from face region under JPEG-compression attacks (Different compression ratios).

Compression ratio	3.26	7.31	13.01
PSNR after attack	31.12	25.08	23.52
Extract watermark	IVML	IVML	IVML
Correlation	0.992	0.979	0.956

Table 3. Watermark extraction from face region of Figure 2(e) under sharpening, blurring and mixed attacks

Image operations	*Blur*	*Sharpen*	*Sharpen+Blur+JPEG compression r=2*.15	*Sharpen+Blur+JPEG compression r=*4.31
PSNR after attack	28.88	23.13	26.27	22.32
Extract watermarks	IVML	IVML	IVML	IVML
Correlation	0.952	0.991	0.983	0.969

6. References

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