Watermarking Experiments Based On Wavelet Transforms

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A Proposed Watermarking Scheme

A general watermarking scheme includes

(a) a watermark acquisition: Sampling $N(0, 1)$ with a *private seed.*

(b) a watermark embedding: insert the watermark into *wavelet coefficients.*

(c) a watermark extraction and verification

Criteria for a Watermark to Meet

- **Transparency:** The watermark should be perceptually invisible or its presence should not be confused with the image being protected.
- **Robustness:** The watermark should still be detected after the image has undergone linear or nonlinear operations (attacks) such as median filtering, cropping, scaling, compression, and enhancement.
- **Capacity:** The watermarking strategy must be of allowing multiple watermarks to be embedded into an image with each image still being independently verifiable.

Watermark Embedding

Let $\{X(i,j)\}$ be a gray level image of size $N_1 \times N_2$, and let $c_0 = 1/\sqrt{2}$, $c_1 = 1/\sqrt{2}$, define

$$H = \begin{bmatrix} c_0 & c_1 & & & & & & & & \\ c_0 & -c_1 & & & & & & & & \\ & & c_0 & c_1 & & & & & & \\ & & c_0 & -c_1 & & & & & & \\ & & & & \ddots & & & & & \\ & & & & & \ddots & & & & \\ & & & & & & c_0 & c_1 & & \\ & & & & & & c_0 & -c_1 & & \\ & & & & & & & & c_0 & c_1 \\ & & & & & & & & c_0 & -c_1 \end{bmatrix}$$

Then Haar wavelet transform [?] of X can be written as

$$Y = P \bigotimes_4 H \bigotimes_3 X \bigotimes_1 H^t \bigotimes_2 Q \tag{1}$$

where $\otimes_j$ is an ordered matrix multiplication, and P, Q are the products of row and column permutation matrices, respectively, for the purpose of downsampling for a coarser wavelet transform.

Watermarking Embedding (2)

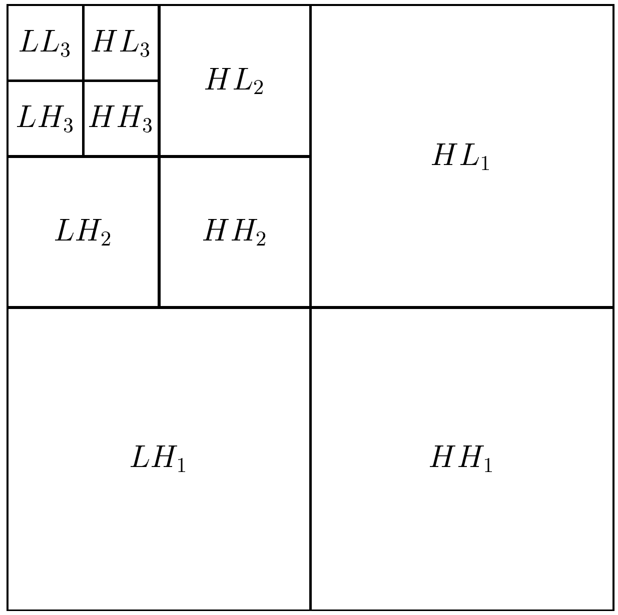

Figure 1: A 3-Scale Wavelet Transform.

where $Y_1 = HL_3 = H_{HL3}(X)$ and $Y_2 = LH_3 = H_{LH3}(X)$ are images consisting of wavelet coefficients of high-low and low-high bands at level 3 whose sizes are both $M_1 \times M_2$, where $M_1 = N_1/8$ and $M_2 = N_2/8$, respectively. Let W be a watermark of size $M_1 \times M_2$ which is acquired by sampling $N(0,1)$, a Gaussian distribution with zero mean and unit variance. Our embedding scheme is done pointwise by

$$Y_1 \longleftarrow Y_1 * (1 + \alpha W) \tag{2}$$

$$Y_2 \longleftarrow Y_2 * (1 - \alpha W) \tag{3}$$

where $\alpha \in (0, 0.3]$.

Watermarking Extraction and Detection

Let $\{X(i,j)\}$ be the original image of $N_1 \times N_2$, and let $\{W(i,j)\}$ be an authorized watermark, a matrix of $M_1 \times M_2$. Suppose that $\{Y(i,j)\}$ is an observed image of $N_1 \times N_2$, then the extracted watermark W^* can be computed by the following formulas:

$$Z = H_{HL3}(X) \quad or \quad Z' = H_{LH3}(X) \tag{4}$$

$$T = H_{HL3}(Y) \quad or \quad T' = H_{LH3}(Y) \tag{5}$$

$$W^*(i,j) = \frac{1}{\alpha}[T(i,j)/Z(i,j) - 1] \quad or \quad W^*(i,j) = \frac{-1}{\alpha}[T'(i,j)/Z'(i,j) - 1] \quad or \tag{6}$$

$$Sim(W^*, W) = (W^*, W)/\sqrt{(W^*, W^*)} \tag{7}$$

According to a theorem of Probability Theory, $\{W(i,j)\}$ can be treated as a random sample of size K=$M_1 \times M_2$ from $N(0,1)$, and $\{W^*(i,j)\}$ is a set of K numbers, thus, $Sim(W^*, W) \sim N(0,1)$. Therefore, the two-sided confidence interval of $Sim(W^*, W)$ is $[-1.96, 1.96]$, which helps determine the *significance* of the $Sim(W^*, W)$ index or the existence of an extracted watermark.

Experimental Results

Haar	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5	Exp-6	Exp-7	Exp-8
PSNR	41.29	30.46	33.96	45.95	33.34	32.60	30.51	36.01
Sim	41.95	2.66	3.33	23.17	3.40	3.41	2.91	3.12

Table 1: **PSNR and Sim of Watermarked Lenna, lena0, Under Attacks.**

(a) (b)

Figure 2: (a) Lenna, (b) lena0: A Watermarked Image.

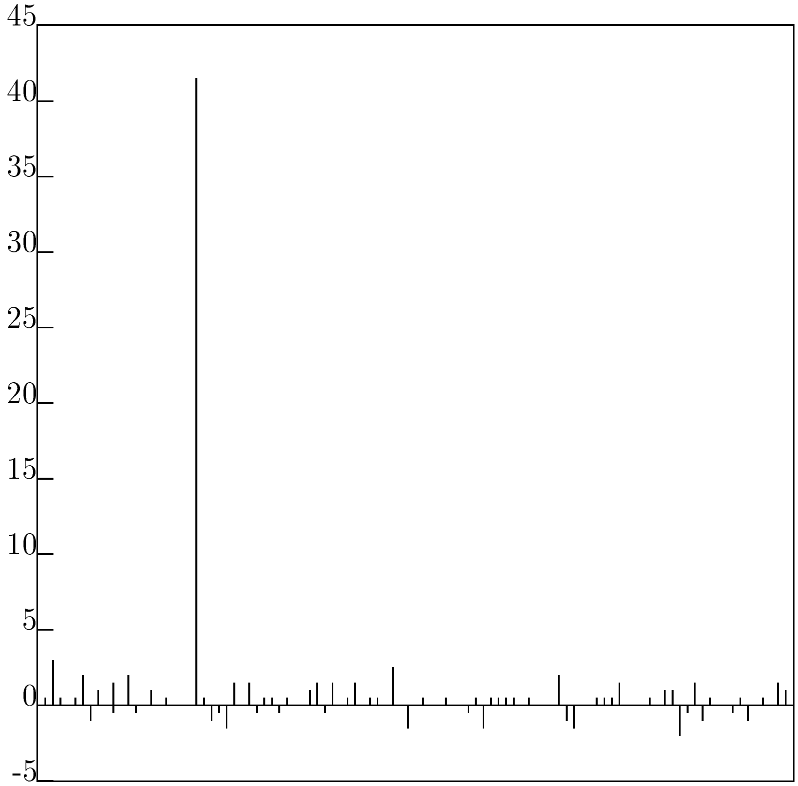

Figure 3: 99 Sim values of random watermarks vs. a true one.

Figure 4: Scaling

Figure 5: Smoothing

Figure 6: Cropping

Figure 7: Noise-Adding

Figure 8: JPEG Compression

Figure 9: Fractal Compression

Figure 9: Wavelet Compression