Watermarking based on the Hyperanalytic Wavelet Transform

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It-is the Watermarking a Communications Matter?

- Digital watermarking
  - embedding of information (watermark) in media signals without perceptible changes
  - copyright protection and ownership identification

Pro: Authentication, image compression (JPEG 2000),…

Generally speaking not yet!

Workshop “Trends and Recent Achievements in Information Technology” Cluj-Napoca, 2002: Prof. Monica Borda, Prof. Karen Eguazarian, Prof. Ioan Nafornta, C. Serdean,…

Embedding in the domain of a redundant wavelet transform.
Requirements

- Robustness
- Perceptual embedding

Capacity
- Redundance

Imperceptibility
- Perceptual embedding

How?

Perceptual Embedding in the Domain of a Non-redundant Wavelet Transform

Method 1
They use only the first decomposition level of the DWT.

Perceptual watermarking

The quantization step: \[ q^\omega(i, j) = \frac{\Theta(i, \theta)}{\Lambda(l, i, j) \Gamma(l, i, j)^{0.2}} \]

\[ \Theta(i, \theta) = \begin{cases} \sqrt{2}, & \theta = 1 \\ 1, & \text{otherwise} \end{cases} \]

\[ \Lambda(l, i, j) = 1 + L'(l, i, j) \]

\[ L'(l, i, j) = \begin{cases} 1 - L(l, i, j), & L(l, i, j) < 0.5 \\ L(l, i, j), & \text{otherwise} \end{cases} \]

\[ L(l, i, j) = \frac{1}{256} \left( 1 + \frac{i}{2^l} \right) \left( 1 + \frac{j}{2^l} \right) \]

→ the texture content is computed using the approximation image hence it has a low resolution

\[ \Xi(l, i, j) = \sum_{k=0}^{\infty} \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \left[ f_{x,y}(y + \frac{i}{2^l}, x + \frac{j}{2^l}) \right]^2 \cdot \text{Var} \left[ f_{x,y}(y + \frac{i}{2^l}, x + \frac{j}{2^l}) \right] \]
Detection

• Blind detection, correlation at each decomposition level, \( l \), marked and attacked DWT coefficients, the watermarking sequence, comparison with a threshold \( T \):

\[
\rho(l) = \frac{4^l}{3MN} \sum_{i=0}^{2^{M-1}} \sum_{j=0}^{N/2^{l-1}} a_{i,j}^0 \cdot x_i^0(i,j)
\]

• Two hypotheses:
  – Watermark embedded,
  – Watermark not embedded.

In each case the central limit theorem can be applied \( \Rightarrow \) for both hypotheses \( \rho \) is Gaussian distributed \( \Rightarrow \) there are tables for the computation of the probability of false alarm \( P_f \).

For \( P_f \leq 10^{-8}, T = 3.97 \sqrt{\frac{2}{\sigma_{\rho}^2}} \)

Disadvantages

• Embedding - only in the highest resolution level, the watermark information can be easily erased by a potential attacker.

• The mask has low resolution.
Method 2 - Improved mask


A modified perceptual mask → models the human visual system behavior in a better way;

Embedding → in all detail sub-bands except the coarsest level, for attack resilience;

Ratio correlation / image dependent threshold → detection function nonlinear with a fixed detection threshold

• Three types of detectors that take advantage of the wavelet hierarchical decomposition.

1) from all resolution levels, all_levels
2) separately, considering the maximum detector response from each level, max_level
3) separately, considering the maximum detector response from each subband, max_subband
Masks for method 1 & method 2

Watermark Detection

Three types of detectors:
1) **all_level**
   \[ d_1 = \frac{\rho_{d1}}{T_{d1}} \]

2) **max_level**
   \[ d(l) = \frac{\rho(l)}{T(l)}, \ l \in \{0,1,2\}, \]

3) **max_subband**
   \[ d(l, \theta) = \frac{\rho(l, \theta)}{T(l, \theta)}; \ l, \theta \in \{0,1,2\}, \]
   \[ d_2 = \max_l \{d(l)\} \]
   \[ d_3 = \max_{\theta,l} \{d(l, \theta)\} \]
Method 3. Perceptual Embedding in the Domain of a Redundant Wavelet Transform

- Recently was proposed a new complex wavelet transform, the hyperanalytic wavelet transform (HWT).
- We have developed last year a new implementation of HWT.
- The aim of this paper is to present the adaptation of the watermarking method proposed by Corina Naftonita in her PhD. thesis to the HWT and to study the robustness of this new technique.

Hyperanalytic Wavelet Transform

If $\psi$ is a one-dimensional mother wavelets then $a\psi = \psi + iH\{\psi\}$ is also a mother wavelets

\[
\text{DWT}\{x\} = \langle x, \psi_{m,n}\rangle;
\]

\[
\text{DTCWT}\{x\} = \langle x, a\psi_{m,n}\rangle - \text{analytic wavelet transform}
\]

Its two-dimensional generalization is named Hyperanalytic Wavelet Transform.
The analytic wavelet transform is similar with the Double Tree Complex Wavelet Transform (DTCWT).

- Loo and Kingsbury proved that the capacity of a watermarking system can be increased working with complex wavelets:
  
  Patrick Loo and Nick Kingsbury, DIGITAL WATERMARKING USING COMPLEX WAVELETS, ICIP 2003.

- They worked with the DTCWT. Because the HWT is similar with the DTCWT, we believe that the capacity of the watermarking system increases if it is based on our implementation of the HWT.
Hyperanalytic Mother Wavelet

\[ \psi_a(x, y) = \psi(x, y) + i\mathcal{H}_x \{\psi(x, y)\} + \]
\[ + j\mathcal{H}_y \{\psi(x, y)\} + k\mathcal{H}_x \{\mathcal{H}_y \{\psi(x, y)\}\} \]

\[ i^2 = j^2 = -k^2 = -1, \text{ and } ij = ji = k \]

Hyperanalytic Wavelet Transform

\[ HWT\{f(x, y)\} = \langle f(x, y), \psi_a(x, y) \rangle. \]
\[ HWT\{f(x, y)\} = DWT\{f(x, y)\} + \]
\[ iDWT\{\mathcal{H}_x \{f(x, y)\}\} + jDWT\{\mathcal{H}_y \{f(x, y)\}\} + \]
\[ + kDWT\{\mathcal{H}_x \{\mathcal{H}_y \{f(x, y)\}\}\} = \]
\[ \langle f_a(x, y), \psi(x, y) \rangle = DWT\{f_a(x, y)\}. \]
Enhancement of Directional Selectivity

Method 3

The watermark is embedded into the coefficients $z_{+r}$ and $z_{-r}$ using in each case the method 2.
Watermark Embedding

- The watermark is embedded using the mask 2 independently for each of these two images.
  - the orientations $\theta$ (preferential directions):
    - $\atan(1/2)$, $\pi/4$, $\atan(2)$ (respectively for $\theta = 0, 1, 2$), for $z_r$
    - $-\atan(1/2)$, $-\pi/4$, $-\atan(2)$, ($\theta=0,1,2$) for $z_r$
- At the detection side, we consider the pair of images $(z_{+r}, z_{-r})$ with twice as much coefficients than the standard approach.
Simulation results

- Method 3, watermarking at levels \( l \in \{0, 1, 2\} \) with the new mask in real images \( z_+, z_- \).
- Embedding strength \( \alpha = 1.5 \), PSNR=35.63 dB
- Method 2, \( \alpha = 1.5 \) and \( l \in \{0, 1, 2\} \rightarrow \text{PSNR}=36.86\text{dB} \)
- Method 1, ONLY first resolution level, \( l=0 \), for \( \alpha=0.2 \rightarrow \text{similar image quality, PSNR}=36.39 \text{dB} \)
- Constant for comparison:
  - Image Lena 512×512,
  - the 2D watermarks embedded in the first level,
  - the image quality.
Original and watermarked images with method 3, for $\alpha = 1.5$, PSNR=35.63 dB; Difference image, amplified 8 times.
• Embedding in the real parts of the HWT transform yields in a **higher capacity** at the same visual impact and robustness.
• The results concerning the robustness against attacks are similar with the results of the watermarking methods based on DWT.

**Conclusion**

• We proposed a new type of pixel-wise masking for robust watermarking method based on a simple implementation of the HWT, a very modern WT:
  – a flexible structure,
  – a high degree of shift-invariance,
  – enhanced directional selectivity.
• Modifications made to two existing watermarking techniques 1 and 2, based on DWT.
• These techniques were selected for their good robustness against the usual attacks.
• The method 2 was inspired by the method 1, but it contains some modifications.
Future Research Directions

– Closer analysis on the effects of using realisable Hilbert transformers as the next step of HWT implementation development,
– Use of an image database,
– Consideration of other geometrical attacks (i.e. rotation), taking into account the better directional selectivity of the HWT.