A Multiresolution Robust Watermarking Approach for Scalable Wavelet Image Compression

Habibollah Danyali and Mehran Deljavan Amiri

Department of Electrical Engineering
University of Kurdistan, Sanandaj, Iran
hdanyali@ieee.org, mehran_deljavan@yahoo.com

Abstract. This paper proposes a multiresolution blind watermarking approach in wavelet domain. The proposed approach performs a multiresolution decomposition of the logo (watermark) image. The logo insertion is started from the lowest frequency subband of the decomposed image and each decomposed logo subband is inserted into its counterpart subband of the decomposed image. The watermarked image does not show any perceptual degradation. To test the scalability features of the approach and robustness of the watermark against image compression, the watermarked image was first encoded by a highly scalable modification of SPIHT and then decoded at different bitrates and spatial resolutions. Multiple spatial resolution levels of the logo is progressively detectable from the decoded watermarked image. Experimental results confirm scalability features of the approach and its robustness against lossy compression. This approach could efficiently provide security for visual image transmission especially over heterogenous networks, where different end-users need to be differently (in quality and resolution) served according to their device capability and network access bandwidth.

1 Introduction

Digital image watermarking refers to the process of embedding a watermark (an authentication message such as text, sound or logo image) into the host image content which uniquely identifies the data holder's ownership. This process is highly necessary to secure digital data against unauthorized use and distribution. With the advance of data digitization and ease of digital data exchange over the Internet, nowadays copyright and ownership protection for digital data has become more important and a very competitive field of research.

For a good image watermarking, the watermarking system should satisfy the following requirements: Transparency, robustness, security and appropriate complexity [1]. Transparency requires that the watermark should not perceptually degrade the quality of the host image. Robustness means that the watermark should withstand against common processing of the watermarked image such as compression, filtering, cropping and rotation and intentional attacks as well. Security implies that the embedded watermark must not be easily detectable by unauthorized users. Appropriate complexity refers to the fact that the complexity and memory requirements for implementing of the watermark embedding/extraction algorithms should be small relative to the coding/decoding processes especially for real-time applications.

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Watermark insertion can be performed in the spatial domain or in the transform domain. The spatial domain watermarking methods are directly performed to the original image pixels. On the other hand, the transform domain watermarking methods are performed to the coefficients of transformed image after applying a transform such as DFT (discrete Fourier transform), DCT (discrete cosine transform) or DWT (discrete wavelet transform) to the original image. From detection point of view, watermarking methods are classified into non-blind and blind methods. In non-blind case, the original image is required in the detection process of watermark, while in blind case the watermark data is detectable in absence of the original image.

Scalability in image coding context refers to a potential in the coded bitstream that allows the decoder to usefully decode from only parts of the bitstream in order to meet certain quality and/or spatial resolution requirements. A scalable coded bitstream consists of a set of embedded parts that offer increasingly better signal-to-noise ratio (SNR) (known as SNR scalability or quality scalability) or higher spatial resolution (referred to as spatial scalability) [2]. Scalability is an important requirement for efficient image archiving and transmission. It also enables the hierarchical search of an image database from low resolution/quality images toward high resolution/quality, which can effectively speed up the search operation. For image distribution applications, especially over heterogenous networks such as the Internet, the scalability feature enables a wide range of end-users with different processing and network access bandwidth to be served all from one embedded bitstream. In a scalable image coding scenario, the watermarked image is encoded by a scalable image compression algorithm therefore it is necessary to design a scalable watermarking scheme as well, where the watermark is also detectable to the required quality and resolution levels.

Over the past decade, wavelet-based image compression schemes have become increasingly important and gained widespread acceptance. An example is JPEG2000 still image compression standard [3, 4]. Due to the multiresolution signal representation offered by the wavelet transform, wavelet based coding schemes have a great potential to support scalability features. Among the state-of-the-art embedded wavelet coding approaches, the Set Partitioning in Hierarchical Trees (SPIHT) algorithm [5] is well known as a benchmark for its compression efficiency, full SNR scalability support and very low complexity. On the other hand, research conducted by Pearlman [6] showed a very significant complexity reduction of SPIHT over JPEG2000.

Several researches on digital image watermarking suitable for wavelet-based compression have been reported in the literature [7, 8, 9, 10, 11]. These methods attempt to provide robustness of the watermark against wavelet-based compression, however non of them provide full scalability (i.e., both SNR and spatial scalability features) for watermark detection. In [9] a secret message is directly embedded in a SPIHT encoded image which enables the decoder to progressively (only by quality) reveal the secret message during the decoding process. The watermarking scheme designed in [8] first decomposes the watermark into a pyramid of low resolution image and higher level differences and then adds to the DWT coefficients of the host image. Although this scheme is suitable for SNR scalable transmission, it does not support multiresolution detection of the watermark and moreover is a non-blind method which requires the original image for decoding process. In this paper, we propose a full scalable blind watermarking in combination with a SPIHT-based coding system. The watermarked image is robust against lossy decoding and combined SNR and spatial scalability for both watermark and the host image is provided. The encoded bitstream is suitable for progressive transmission specially over heterogenous network where different users with different capabilities require different services. The host image and the watermark can be decoded at various spatial resolution levels progressively at any bitrate.

The rest of this paper is organized as follow. Section 2 gives an overview of the proposed system. In Section 3, watermark insertion and extraction algorithms is presented. The HS-SPIHT algorithm employed for coding is briefly explained in Section 4. In Section 5, some details about the simulation of the coding system are given and experimental results for scalable lossy decoding are presented, and finally, Section 6 concludes the paper.

2 Overview of the Proposed System

The proposed system is depicted in Figure 1. On the encoder side the input image is first transformed to wavelet domain by applying multi-level of 2D-DWT to provide the wavelet coefficients pyramid (see Figure 2). a multiresolution decomposition of the binary logo which used as a watermark data is also provided by multi-level 2D downsampling of the logo as shown in Figure 3. The components in different subbands (seven subbands in Figure 3) of the decomposed logo are then inserted into the coefficients of the appropriate subbands (seven top level subbands in Figure 2) of the decomposed image. Details of the logo insertion and detection algorithms are given in

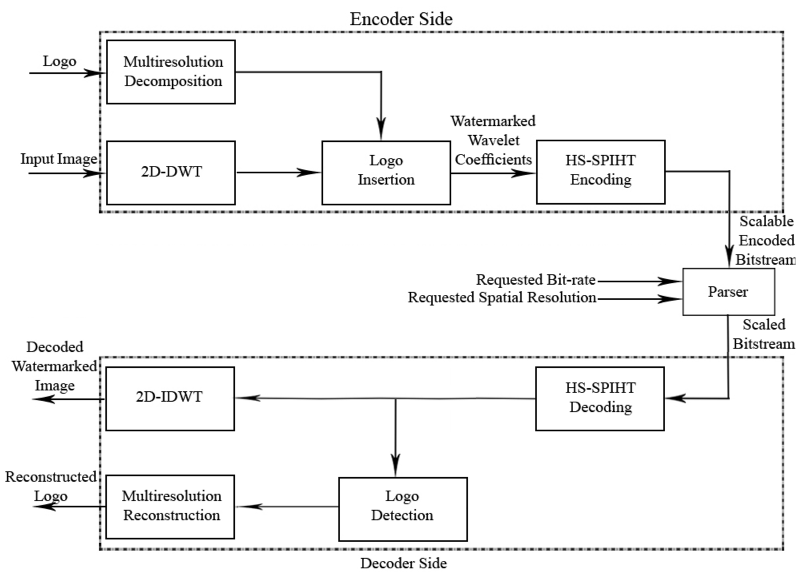

Fig. 1. Block diagram of the proposed system

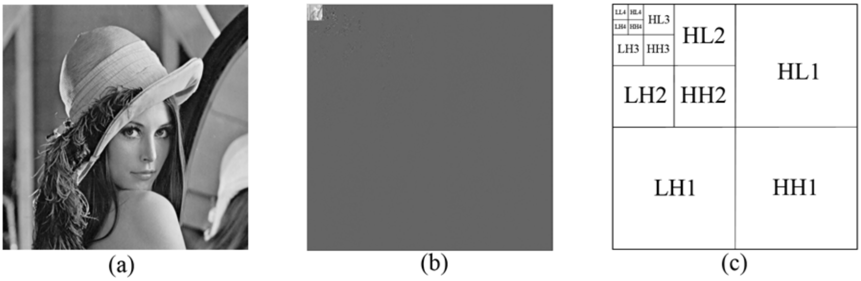

Fig. 2. (a) 512×512 Lena image, (b) decomposed Lena after applying 4-levels of 2D DWT, (c) convention of (b)

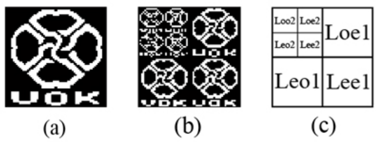

Fig. 3. (a) 64×64 logo image, (b) decomposed logo after applying 2-levels of 2D downsampling, (c) convention of (b)

Section 3. The watermarked DWT coefficients are encoded by a highly scalable version of SPIHT [5], called HS-SPIHT [12, 13] that provides an SNR and spatial scalable bitstream. HS-SPIHT is breifly explained in Section 4. In a parsing stage , the scalable encoded watermarked image bitstream is reordered and truncated by a parser to provide proper bitstreams for the qualities (bitrates) and spatial resolutions requested by various decoders (end users). On the decoder side the input scaled bitstream is decoded by the HS-SPIHT to progressively (by quality) reconstruct the watermarked DWT coefficient for the target spatial resolution. By applying a multi-level inverse 2D-DWT to the decoded coefficients the watermarked image for the decoder rate and resolution is reconstructed. At a logo detection step, binary data of the multiresolution decomposed logo (Figure 3) is extracted from the reconstructed DWT coefficients, from which multiple spatial resolution of the logo is reconstructed.

3 Watermark Insertion and Detection Algorithms

The lower frequency subbands of the wavelet decomposed image are perceptually more important parts of the image and remain more robust against attacks. Therefore watermark insertion in the proposed algorithm is started from the lowest frequency band of the decomposed image and continued toward the higher frequency according to the number of multiresolution applied to the binary logo image (see Figure 4). On the other hand, insertion of strong watermark to the low frequency subbands could have negative impact on the transparency of the watermarked image, therefore the watermark insertion should be carefully designed.

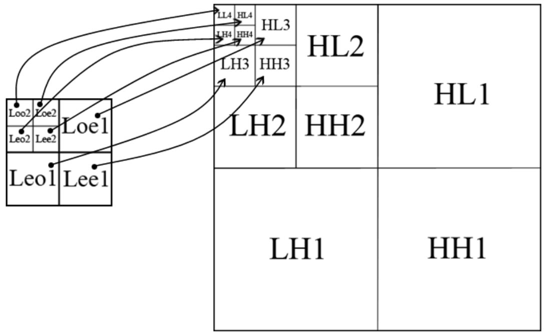

Fig. 4. Corresponding subbands in the reconstructed logo and the wavelet decomposed image

Watermark insertion algorithm

- **Step 1:** Apply 4 levels of a 2D-DWT to the original image, $I(x, y)$, to generates the decomposed image, $W(x, y)$, which consists of one low frequency subband (LL_4) and 12 high frequency subbands (HL_i, LH_i, HH_i, for i=1 to 4) (see Figure 2). These subbands are classified according to their dependency to spatial resolution levels as follow:
  WSL(5) = $\{LL_4\}$;
  WSL(i) = $\{HL_i, LH_i, HH_i\}$ for i=1 to 4.
  WSL stands for Wavelet Subband Level.
- **Step 2:** Apply 2 levels of a 2D down-sampling to the binary logo image, $L(x, y)$, to generates 7 subbands , Loo_2 and Loe_j, Leo_j and Lee_j, j=1,2 (see Figure 3). Also, these subbands are classified as follow:
  LSL(3) = Loo_2;
  LSL(i) = $\{Loe_i , Leo_i , Lee_i\}$; for i=1,2.
  LSL stands for Logo Subband Level.
- **Step 3:** for (i=1 to 3)$\{$
  insert LSL(i) into WSL(i+2) as follows:

  - for each component(l) in the LSL(i) and its corresponding coefficient (w) in the WSL(i+2)$\{$
    $w \gg (i + 3); w \ll (i + 3)$
    $w = w + l \times 2^{i+2}$;
    $\}$

  $\}$

Watermark detection algorithm

- **Step 1:** Apply 4 levels of a 2D-DWT to the decoded image. The decomposed image is named $W_d(x, y)$ and the subbands in $W_d(x, y)$ are classified in different subband levels ($WSL_d(i)$), the same way as done in the insertion procedure.

- **Step 2:** for (i=1 to 3){
  extract LSL$_d(i)$ from WSL$_d(i$+2) as follows:

  - for each coefficient(w_d)in the WSL$_d(i$+2){
    if (w_d mod 2^{i+3}) equals (w_d mod 2^{i+2}) then l_d=1;
    else l_d=0 }

  }
- **Step 3:** take LSL$_d$(3) as detected logo at quarter resolution;
  take LSL$_d$(3) and LSL$_d$(2) and apply one level reconstruction (i.e. inverse of the 2D downsampling done in the insertion stage) to obtain detected logo at half resolution;
  take LSL$_d$(3), LSL$_d$(2) and LSL$_d$(1) and apply two levels reconstruction to obtain detected logo at full resolution;

4 HS-SPIHT Algorithm

The SPIHT algorithm [5] is a bitplane coding process. The core of its high compression performance is grouping of the wavelet coefficients in sets and sorting and managing these sets in a hierarchical structure in order to efficiently identify and extract sets of insignificant and significant coefficients in each bitplane coding level. It provides a progressive (by quality), fully SNR scalable bitstream, however, spatial scalability is not supported. In our previous works [12, 13] we proposed a highly scalable modification of SPIHT, called HS-SPIHT, through the introduction of multiple resolution-dependent lists and a resolution-dependent sorting pass.

A wavelet decomposed image with N levels of 2D decomposition provides at most $N+1$ different spatial resolution levels.We denote the lowest spatial resolution level as level $N+1$. The full resolution (the original sequence) then becomes level 1. To increase the spatial resolution from level $k+1$ to the next higher resolution level (i.e. level k), the set of three subbands (HL$_k$, LH$_k$, HH$_k$) known as wavelet subbands of level k(WSL(k), see Section 3) is required to be added to this resolution. The HS-SPIHT algorithm encodes WSL(k) in the wavelet decomposed image separately, allowing a parser or a decoder to directly access the data needed for reconstruction of a desired spatial resolution and/or quality. HS-SPIHT adds spatial scalability feature to SPIHT without sacrificing compression efficiency, progressiveness and low complexity features of the SPIHT.

5 Experimental Results

The proposed system was fully software implemented. Four gray scale images (8 bits per pixel), Lena, Barbara, Goldhill and Boat were used as test images. The size of these images is 512×512. A 64×64 binary image shown in Figure 3(a) was used as logo (watermark). Four levels of 2D-DWT, with Daubechies 9/7 filter banks [14] were applied to each test image. Two levels of a 2D downsampling were used to provide a multiresolution decomposition of the binary logo image (see Figure 3(b)). This decomposition

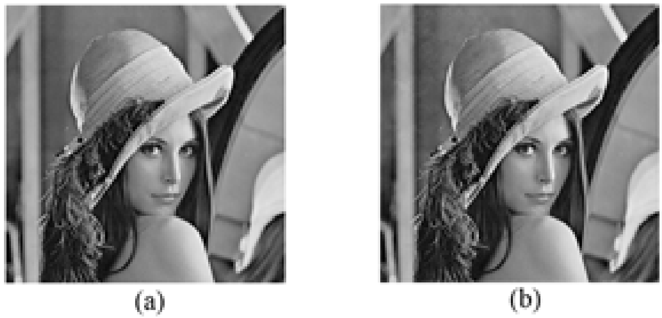

Fig. 5. (a) Original Lena (512 × 512), (b) Watermarked Lena (PSNR = 47.30dB)

could provide three levels of spatial resolution for logo (i.e. full, half and quarter resolutions at each spatial dimension). The decomposed logo was then inserted to the three top resolution levels of subbands of the decomposed wavelet coefficients.

To test the transparency of the proposed watermarking method, the watermarked image was directly (without coding) reconstructed by applying four levels of inverse 2D-DWT to the watermarked wavelet coefficients. Figure 5 shows the original and watermarked Lena images. The watermarked image does not show any perceptual degradation and its PSNR is 47.30dB.

To test robustness of the watermark against lossy compression and the full scalability features of the proposed system for both watermark and the host image, a scenario

Table 1. Results for lossy decoding of the compressed HS-SPIHT bitstreams at full spatial resolutions(512 × 512)

Rate (bpp)	Lena					Barbara				
	PSNR-W (dB)	PSNR-I (dB)	BER			PSNR-W (dB)	PSNR-I (dB)	BER		
			Quarter	Half	Full			Quarter	Half	Full
2	42.29	43.91	0	0	0	40.70	41.83	0	0	0
1	38.93	39.62	0	0	0	35.00	35.30	0	0	0
0.5	36.04	36.44	0	0	0	30.31	30.38	0	0	0.169
0.4	35.33	35.56	0	0	0.188	29.10	29.13	0	0.105	0.244
0.3	33.83	34.00	0	0	0.188	27.14	27.16	0	0.105	0.244
0.2	32.09	32.14	0	0.157	0.259	25.86	25.87	0	0.229	0.284
Rate (bpp)	Goldhill					Boat				
	PSNR-W (dB)	PSNR-I (dB)	BER			PSNR-W (dB)	PSNR-I (dB)	BER		
			Quarter	Half	Full			Quarter	Half	Full
2	39.71	40.60	0	0	0	42.30	43.87	0	0	0
1	35.26	35.58	0	0	0	37.55	38.13	0	0	0
0.5	32.14	32.24	0	0	0.152	33.17	33.33	0	0	0.195
0.4	31.32	31.41	0	0	0.153	32.05	32.16	0	0	0.195
0.3	30.40	30.47	0	0	0.202	30.89	30.93	0	0.173	0.267
0.2	29.00	29.03	0	0.116	0.247	28.77	28.80	0	0.173	0.267

Table 2. Results for lossy decoding of the compressed HS-SPIHT bitstreams at quarter spatial resolutions(128 × 128)

Rate (bpp)	Lena PSNR-W (dB)	Lena PSNR-I (dB)	Lena BER Quarter	Lena BER Half	Lena BER Full	Barbara PSNR-W (dB)	Barbara PSNR-I (dB)	Barbara BER Quarter	Barbara BER Half	Barbara BER Full
0.5	47.66	69.82	0	0	0	47.57	69.98	0	0	0
0.4	47.54	63.24	0	0	0	47.31	60.01	0	0	0
0.3	46.59	53.87	0	0	0	45.50	50.54	0	0	0
0.2	43.77	45.37	0	0	0.202	41.06	41.92	0	0	0.196
0.15	39.92	40.59	0	0	0.215	37.38	37.57	0	0.175	0.249
0.1	35.01	35.12	0	0.195	0.274	33.24	33.24	0	0.187	0.267

Rate (bpp)	Goldhill PSNR-W (dB)	Goldhill PSNR-I (dB)	Goldhill BER Quarter	Goldhill BER Half	Goldhill BER Full	Boat PSNR-W (dB)	Boat PSNR-I (dB)	Boat BER Quarter	Boat BER Half	Boat BER Full
0.5	47.40	70.15	0	0	0	47.82	69.76	0	0	0
0.4	47.17	60.43	0	0	0	47.57	61.65	0	0	0
0.3	45.53	50.82	0	0	0	46.30	53.13	0	0	0
0.2	41.06	41.89	0	0	0.185	42.45	43.77	0	0	0.207
0.15	37.70	37.91	0	0.175	0.246	38.61	38.87	0	0.200	0.267
0.1	33.38	33.45	0	0.188	0.268	33.54	33.54	0	0.212	0.275

of once encoding, multiple times decoding at various bitrates (qualities) and spatial resolutions levels is used. The watermarked wavelet coefficients were encoded by the HS-SPIHT encoder. The encoder was set to support maximum required bitrate and maximum spatial scalability support. Note that, using 4 levels wavelet decomposition for the image, enables encoder to support maximum 5 spatial resolution levels.

Table 1 shows the results of decoding the watermarked image at full spatial resolution (i.e. 512×512) and different birates. PSNR (Peak Signal-to-Noise Ratio) is used to measure the quality of the decoded image. In this table PSNR-W shows the quality of the decoded watermarked image at each bitrate. PSNR-I which shows the quality of the decoded original image without inserting watermark, is also provided for comparison. The fidelity of the reconstructed binary logo was measured by BER (Bit Error Rate) which is defined as:

$$\mathrm{BER} = \frac{\text{number of false reconstructed components}}{\text{total number of components in the logo}}$$

if the BER is zero, the original and reconstructed logos are the same, however if it is one indicates complete absence of the logo. Table 2 shows the similar results as Table 1 but for decoding the watermarked image at quarter spatial resolution (i.e. 128×128).

For each bitrate in Table 1 and Table 2, the logo is detected at 3 different resolutions(i.e., Quarter, half and full). As the results show, a low resolution logo is completely detectable at low bitrates, while higher resolution is achievable by spending more coding budget. The capability of multiresolution logo detection provides more security for the watermarked image, because even at very low bitrate, at least a low resolution version of the logo is completely detectable. The small difference between PSNR-W and

PSNR-I in Table 1, especially where the logo is completely detectable at all resolutions, clarifies this fact that the portion of the bitrate spent for coding of the logo information in the watermarked image is negligible. Note that the PSNRs in Table 2 are high and therefore very sensitive to the small changes in the decoded image.

At the same bitrate, the PSNR and BER results in Table 2 are much better than Table 1. The reason is that, when we target a lower spatial resolution, the coding budget spent for higher subbands coding at full resolution coding case, is now spent for the lower resolutions which also contain logo information. Therefore more budget is spent for both lower resolution image and logo as well and consequently the quality of the reconstructed the watermarked image and logo in this case is better.

6 Conclusions

A multiresolution blind watermarking approach for scalable wavelet-based image compression was introduced. A 64×64 binary image was used as logo (watermark). A multiresolution decomposition of the logo was performed by applying 2 levels of binary 2D down-sampling. The decomposed logo subbands were inserted into their corresponding subbands of the wavelet decomposed host image. The performance of the proposed approach was evaluated by lossy compression of the watermarked image by the HS-SPIHT algorithm. The compressed bitstream were decoded at different bitrates and spatial resolutions levels. While at high bitrates, full resolution of the logo was completely detectable, at very low bit rates (e.g., 0.1bpp) still a lower resolution of the logo was detectable, which could authenticate the host image. The PSNR results provided for various test images showed the robustness of the approach against lossy compression. Low complexity, robustness against compression and full scalability support of the proposed approach, make it attractive for secure image transmission applications. Further research will study the performance of the proposed watermarking approach against different non-geometric and geometric attacks.

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