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High Capacity and Low Distortion Reversible Image Watermarking using Integer Wavelet Transform

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***Abstract*— This paper proposes a high capacity reversible image watermarking scheme based on integer wavelet transforms. The proposed scheme divides an input image into non-overlapping blocks and embeds a watermark into the high frequency wavelet coefficients of each block.**

The conditions to avoid both underflow and overflow in the spatial domain are derived for an arbitrary wavelet and block size. The payload to be embedded includes not only messages but also side information used to reconstruct the exact original image. To minimize the mean-squared distortion between the original and the watermarked images given a payload, the watermark is adaptively embedded into the image.

The experimental results show that the proposed scheme achieves higher embedding capacity while maintaining distortion at a lower level than the existing reversible watermarking schemes.

***Key words*— Reversible watermarking, Wavelet transform, watermarking embedding and extraction.**

I. .INTRODUCTION

In digital watermarking, an imperceptible signal referred as a watermark is embedded into multimedia data for various purposes such as copyright protection, fingerprinting, authentication, etc. The embedding of the watermark usually introduces irreversible distortion, although it may be quite small, in the original data. For applications where the availability of original data is essential, irreversible degradation of the original data is not acceptable, and incurred distortions need to be removed. Examples of such applications include multimedia archives, military image processing, and medical image processing for electronic patient records (EPRs). In multimedia archives, a content provider may not want the original content to be distorted even though the distortion is imperceptible to most users, and it may be too costly in terms of storage space to store both the original and the watermarked versions. In military image processing, images are gathered at a very high cost and are usually subjected to further processing steps such as extreme magnification. Any distortion may hinder accurate analysis of the image. In medical image processing, any modification to the original image may affect a doctor's diagnosis and lead to legal problems. Any complications that can occur when using a conventional watermarking scheme in the applications listed above can be resolved by using the reversible (lossless, invertible, erasable, etc.) watermarking scheme. Although the embedding distortion is inevitable even in reversible watermarking, it can be removed, and the original data can be reconstructed from the watermarked version.

When the original content can be recovered from the watermarked content, the watermarking scheme is said to have the invertibility (reversibility) property. Note that the reversibility property can also be obtained using standard (cryptographic) scrambling algorithms. However, the cryptographic approach completely obliterates any semantic understanding, which is not the case in reversible watermarking.

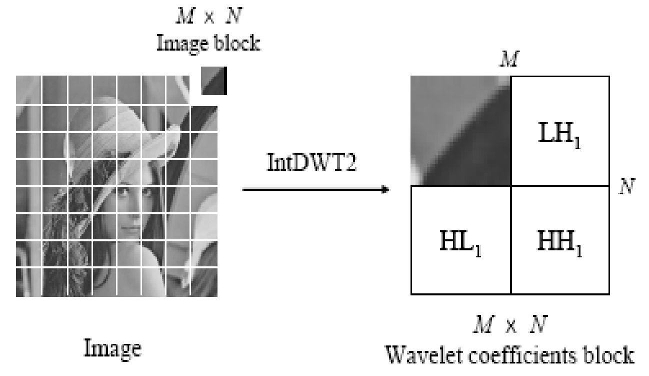

Fig. 1. Watermark is embedded into the high-frequency wavelet subbands, HL_1, LH_1, and HH_1 which are the high-low, low-high, and high-high frequency subbands of each $M \times N$ image block. IntDWT2(·) represents an 2-dimensional integer-to-integer wavelet transform.

In this paper, a novel reversible watermarking scheme with high embedding capacity for digital images is proposed. As shown in Fig. 1, an input image is divided into nonoverlapping blocks, and the watermark is embedded into the high-frequency wavelet coefficients of each block. To achieve the reversibility, invertible integer to-integer wavelet transforms are used, and the conditions to avoid underflow and overflow in the spatial domain are derived for arbitrary wavelets and block sizes. The watermark payload includes not only messages but also side information required to reconstruct the original image at the decoder. Furthermore, the block-based embedding makes the size of the side information that needs to be embedded small in proportion to the total embedding capacity. This advantage enables the proposed scheme to provide higher embedding capacity while maintaining distortion at a lower level than the existing schemes.

The proposed scheme also exploits adaptive embedding to improve the perceptual quality of the watermarked image. Rather than embedding watermark randomly or arbitrarily, the proposed method adaptively embeds watermark to give the highest quality for a given embedding capacity.

II. INVERTIBLE INTEGER WAVELET TRANSFORMS

Conventional wavelet transform is not applicable to the reversible watermarking scheme since it does not guarantee the reversibility. For example, suppose that an image block consisting of integer-valued pixels is transformed into a wavelet domain using a floating-point wavelet transform. If the values of the wavelet coefficients are changed during the watermark embedding, the corresponding watermarked image block is no longer guaranteed to have integer values. Any truncation of the floating-point values of the pixels may result in a loss of information and may ultimately lead to the failure of the reversible watermarking systems, that is, the original image can not be reconstructed from the watermarked image. Furthermore, conventional wavelet transform is in practice implemented as a floating-point transform followed by a truncation or rounding since it is impossible to represent transform coefficients in their full accuracy: information can potentially be lost through forward and inverse transforms. To avoid this problem, an invertible integer-to integer wavelet transform based on lifting is used in the proposed scheme. It maps integers to integers and does not cause any loss of information through forward and inverse transforms.

Every wavelet or subband transform associated with finite length filters can be obtained as the Lazy wavelet followed by a finite number of primal and dual lifting steps and a scaling (the Lazy wavelet essentially splits the signal into its even and odd indexed samples). By combining the lifting constructions with rounding-off in a reversible way, a wavelet transform that maps integers to integers can be obtained. For example, the integer-to-integer wavelet transform that approximates Le Gall 5/3 filters is given by,

$$\begin{aligned} d_{1,n} &= s_{0,2n+1} - \lfloor 1/2(s_{0,2n} + s_{0,2n+2}) + 1/2 \rfloor, \\ s_{1,n} &= s_{0,2n} + \lfloor 1/4(d_{1,n-1} + d_{1,n}) + 1/2 \rfloor \end{aligned} \quad (1)$$

Where $s_{j,n}$ and $d_{j;n}$ are the nth low-frequency and high frequency wavelet coefficients. $\lfloor x \rfloor$ rounds x to the nearest integer towards minus infinity.

III. PREDICTION OF UNDERFLOW AND OVERFLOW

In the proposed scheme, a watermark is embedded into the wavelet coefficients using either the LSB-substitution or the bit-shifting.

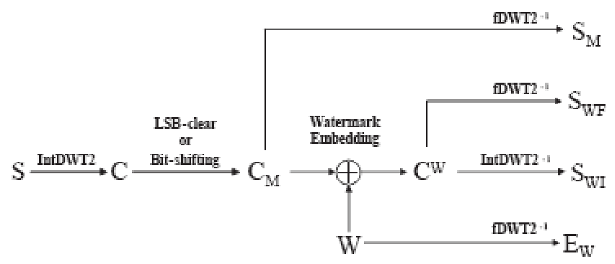

Fig. 2. Forward and inverse wavelet transform, and watermark embedding

When the watermark is embedded in the wavelet domain using either LSB-substitution or bit-shifting, underflow or overflow can occur in the spatial domain. That is, the pixel values obtained from the watermarked wavelet coefficients can either be smaller than the minimum pixel value s_{min} (e.g. $s_{min} = 0$ for 8-bit gray-scale image) or be greater than the maximum value s_{max} (e.g. $s_{max} = 255$ for 8-bit grayscale image). Since the reversibility is lost when underflow or overflow occurs, it must be predicted prior to the watermark embedding. In this paper, underflow and overflow are predicted by identifying the *LSB-changeable* and *bit-shiftable* image blocks.

A. Derivation of Condition to Avoid Underflow and Overflow

In this subsection, the condition to avoid underflow and overflow is derived.The block-wise embedding using wavelet transforms and the notations that will be henceforth used are described in Fig. 2. First, an M x N pixel block S is transformed into a block of M x N wavelet coefficients C using the 2-dimensional nonexpansive integer-to-integer wavelet transform, IntDWT2 (.). Next, a block of modified wavelet coefficients CM is obtained either by setting the LSBs of the chosen wavelet coefficients to zero or by applying bit-shifting to the chosen coefficients in C. The modified pixel block SM is obtained by applying the 2 dimensional inverse floatingpoint ($fDWT2^{-1}$(.)) wavelet transform to C_M. By adding a watermark bit block W to C_M, a block of watermarked wavelet coefficients C^W is obtained. Then, S_{WF} and S_{WI} are obtained by applying $fDWT2^{-1}$(.) and $IntDWT2^{-1}$(.) to C^W, respectively. The embedding error EW is obtained by applying $fDWT2^{-1}$(.) to W. Henceforth, A (m, n) represents an element of the block A in the mth row and the nth column.

When a floating-point wavelet transform is used, underflow and overflow that can occur as a result of embedding a watermark in the wavelet domain can be easily predicted by exploiting the linearity of the transform. Then the watermarked block SWF in Fig. 2 is given by

$$S_{WF} = fDWT2^{-1}(C^W)$$
$$= fDWT2^{-1}(C_M + W)$$
$$= fDWT2^{-1}(C_M) + fDWT2^{-1}(W)$$
$$= S_M + E_W.$$

In the proposed watermarking scheme, integer-to-integer wavelet transforms are used to achieve the reversibility. Therefore, the watermarked image block that we obtain is not S_{WF} but S_{WI} = IntDWT2-1(C^W). Since integer-to integer wavelet transforms involve the truncations of wavelet coefficients during the lifting steps, round-off error is inevitable. Let E_R be the round-off error matrix. Then the watermarked image block S_{WI} is given by:

$$S_{WI} = IntDWT2^{-1}(C^W)$$
$$= IntDWT2^{-1}(C_M + W)$$
$$= fDWT2^{-1}(C_M + W) + E_R$$
$$= S_M + E_W + E_R.$$

B. Distribution of Payload for Adaptive Embedding

Even though the original image can be exactly reconstructed from the watermarked image, the quality of the watermarked image is still important. In this paper, the peak signal-to-noise ratio (PSNR) is used as a measure for quantifying the quality of an image. Therefore, the watermark needs to be embedded such that the mean squared distortion between the original and the watermarked image is minimized.

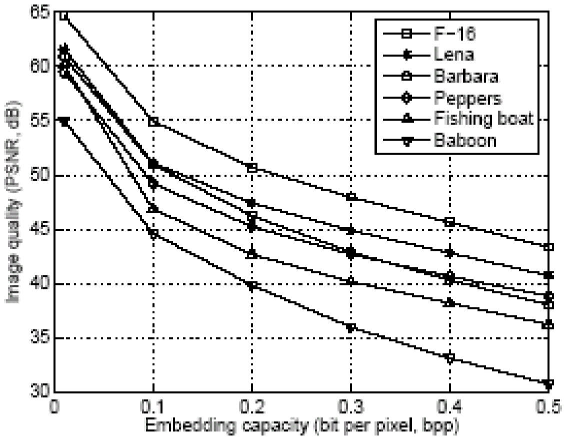

Fig. 4. Comparison of embedding capacity in bpp versus distortion in PSNR for various gray-scale images.

IV.DECODING ALGORITHM

First, the watermarked image is divided into nonoverlapping blocks with dimension M xN, and each block is transformed using the same wavelet used in the embedding procedure. Next, LSB-changeable blocks are searched in a predefined order. In some applications, the order of the search is based on a secret key shared with the embedded. When the LSB-changeable blocks are found, the location map is retrieved by collecting the LSBs of the high-frequency wavelet coefficients in those blocks. Based on the location map, the blocks into which the watermark is embedded are sequentially searched, and the number of embedded bits is calculated by decoding the value of p in each block. Finally, the payload that includes the original LSBs and the message bits is extracted from the blocks indicated by the location map. Using the original LSBs and the location map, the original image block can be reconstructed exactly.

V. EXPERIMENTAL RESULTS

A. Performance for Natural Images with Various Block Sizes

The proposed scheme is applied to various natural images, F-16 (Airplane), Lena, Barbara, Peppers, Fishing boat, and Baboon (Mandrill). Fig. 4 shows the quality of the watermarked images at various embedding capacities up to 0.50 bpp. In this experiment, the block size was set to 16 x 16. As shown in Fig. 4, the proposed scheme achieves high embedding capacity with low distortion. However the capacity-distortion performance depends on the characteristic of

Fig. 5. Original and watermarked gray-scale Lena images (a) original, (b) 44.87 dB with 0.30 bpp, (c) 37.82 dB with 0.65 bpp, and (d) 32.92 dB with 1.00 bpp.

Fig. 6. Original and watermarked gray-scale Barbara images (a) original, (b) 46.23 dB with 0.20 bpp, (c) 38.02 dB with 0.50 bpp, and (d) 31.78 dB with 0.80 bpp.

each image. High embedding capacity could be achieved with low distortion for images that contain large amount of low-frequency components, e.g. F-16 and Lena. On the other hand, for images that include large amount of high frequency components, e.g. Baboon, much lower embedding capacity was obtained at the same PSNR. Fig. 5 and Fig. 6 show the original image and the examples of the watermarked images at various embedding capacities for gray-scale Lena and Barbara images, respectively. As shown in the figures, the perceptual quality of the watermarked image is quite good at low and moderate embedding capacities and is acceptable even at very high embedding capacity around 1.0 bpp. Since the proposed reversible scheme embeds the watermark into the high frequency wavelet coefficients, the high-frequency components of the image are strengthened and the watermarked image seems to be filtered with sharpening mask. However the sharpening effect introduced by the watermark embedding is not perceptually annoying even at low PSNRs.

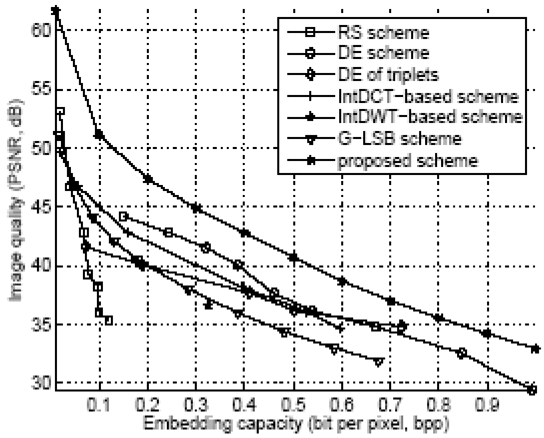

Fig. 7. Comparison of embedding capacity in bpp versus distortion in PSNR with existing reversible schemes — RS , DE , DE of triplets , Integer DCT(IntDCT) , Integer DWT(IntDWT), and Generalized-LSB schemes. The test image is the gray-scale Lena.

B. Comparison of Performance with Other Schemes in the Literature

The performance of the proposed scheme is compared with the existing reversible schemes. Fig. 7 shows the comparison of the embedding capacity in bpp versus distortion in PSNR of the proposed scheme with that of the existing reversible schemes for the gray-scale Lena image. As shown in the figure, the proposed scheme achieves higher embedding capacity at all PSNRs than the other schemes.

VI. CONCLUSION

In this paper, a reversible image watermarking scheme based on integer-to-integer wavelet transforms is proposed. In the proposed scheme, an input image is divided into a number of blocks, and a watermark is embedded into the high-frequency wavelet coefficients of each block via LSB substitution or bit-shifting. The original image can be exactly reconstructed at the decoder since the side information for achieving the reversibility is also embedded in the image while avoiding the underflow and overflow. Experimental results show that the proposed scheme achieves higher embedding capacity at a lower distortion than other existing reversible schemes.

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