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Integer transform based reversible watermarking incorporating block selection ☆

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ABSTRACT

We propose a new scheme based on integer Haar wavelet transform (IHWT), which utilizes block selection and difference expansion (DE) (or histogram shifting (HS)). IHWT has the characteristic that the average of a block remains unchanged before and after watermark embedding. Hence, this invariability can be used for determining whether a block is located in a smooth region or not. Specifically, for a block, its mean value and the neighborhood surrounding it are used for estimating the correlation between it and its neighborhood. In this way, only a reduced size location map is needed, and the block size can also be set to a small value. Since small blocks have stronger intra-block correlation than large ones, the embedding distortion caused by modifying small blocks is lower. Otherwise, if the difference between any two neighboring pixels in a block is large, then the distortion produced by directly expanding it is also high. To decrease the class of distortions, DE (or HS) is introduced into the proposed method.

1. Introduction

In some applications, such as the fields of law enforcement, medical and military image system, any permanent distortion induced to the host images by data watermarking techniques is intolerable. In such cases, the original image is required to be recovered without any distortion after extraction of the embedded watermark. The watermarking techniques satisfying these requirements are referred to as reversible (or lossless) watermarking.

A considerable amount of research on RW has been carried out over the last several years since the concept of RW firstly appeared in the patent owned by Eastman Kodak [1]. Among the various categories of RW schemes, three most influential ones are RW based on lossless compression [2], RW using DE and RW using HS (short for histogram shifting) in [3,4]. RW using DE has been firstly presented by Tian [5]. DE is the process that difference (between a pair of neighboring pixels) is shifted left by one unit to create a vacant least significant bit (LSB), and 1-bit watermark is appended to this LSB. There are different extensions of DE. Among them, three main types of extensions are: RW based on integer transform, RW with the improvement in compressibility of location map and RW using the prediction-error expansion (PEE). DE has been extended to the pixel blocks of arbitrary length by Alattar in [6], Wang et al. in [7,8], and Peng et al. in [9]. Based on integer Haar wavelet transform in [5], the new integer transforms have been proposed in papers [10–13]. Kamstra et al. in [14] and Kim et al. in [15] adopt different embedding strategies so that the location map can be remarkably compressed, respectively. Thodi et al. have proposed the first PEE scheme, wherein the prediction-errors instead of the difference values are expanded [16]. HS is incorporated into Thodi et al.'s method so as to efficiently compress the location map. Afterwards, PEE has also been developed by some recent studies in [17–30]. Among them, Qin et al. have proposed a prediction-based reversible steganographic scheme based on image inpainting. By the use of the adaptive strategy for choosing reference pixels and the inpainting predictor, Qin et al. provide a greater embedding rate and better visual quality compared with recently reported methods. In addition, a lot of RDH algorithms (e.g., [31–34]) have been proposed in the encrypted domain.

Alattar's transform (short for the integer transform proposed by Alattar) can be deemed to contain an additional term and a prediction process, which uses the mean value of a block to predict each pixel in this block [6]. This additional term has its advantage and disadvantage. The advantage is that its existence can guarantee the mean value of a block remains unchanged even after watermark embedding. The disadvantage is that its existence will result in the

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decrease of PSNR (peak signal to noise ratio) in Alattar's method. This is also the reason that the performance of Alattar's method is incapable of exceeding that of Wang et al.'s (see paper [7] for details).

Wang's transform (short for the transform proposed by Wang et al.) can also be considered as a prediction process, in which the mean value of a block is used to predict each pixel in this block [7]. In their method, a location map is generated to record the locations of the modified blocks in the embedding process. In order to ensure reversibility, after this map is losslessly compressed, it is embedded into the original image together with the payload. Hence, the low compression ratio can significantly decrease the payload. Experimental results in [7] demonstrate that when the host image is divided into 4×4-sized blocks, the performance is the best. Although 2×2-sized blocks can provide higher intra-block correlations than 4×4-sized ones, they cannot perform the best. This is due to that when the block size is 2×2, the compression ratio is very low. As a result, the performance is weak. To this end, Wang have to select 4×4 blocks so as to increase embedding performance. However, the performance is not increased largely owing to low intra-block correlation. In this light, it is necessary to investigate high performance RW methods.

Besides, Wang calculate the variance of a block so as to determine the length of the watermark bits embedded into this block. As long as the calculated variance is smaller than a predefined threshold, even if the difference between some pixel and the mean value is large, Wang still embed the corresponding watermark bit into this pixel. In another word, to ensure reversibility, Wang's transform has to modify all the pixels in a block uniformly even if the distortions introduced by modification are high for some pixels.

Considering that a block can embed at most $(n-1)$ data bits in Wang's transform, Peng (short for Peng et al.) have introduced adaptive embedding into Wang's transform, in which a block can embed $(n-1)\log_2 k$ bits, where n is used to denote the size of an image block, and k ($k \in \{1,2,4,8,16\}$) is determined adaptively by the pre-estimated distortion. By the basic idea that embeds more bits into smooth blocks while avoids large distortion generated by noisy ones, Peng's method enables very high capacity with good image quality. However, Peng cannot solve the problems existed in Wang's transform. With the above consideration, we argue that Peng's method can be further improved.

In order to solve two problems above, a novel RW scheme based on block selection is proposed in this paper. We employ the correlation between a block and its total adjacent pixels to determine if this block is located in a smooth or a complex region. These neighboring pixels along with the mean value of this block constitute a set. The correlation is defined as the local variance of this set. As long as the mean value is invariant, the local variance remains unchanged after watermark embedding. This is the reason that the integer transform having the invariant mean value (i.e., Alattar's transform) is selected in this paper. Since the variance is invariant, only a reduced size location map is needed, and the map can be efficiently compressed. Besides, by means of the invariant variance, the locations of all the already-modified blocks in watermark embedding process can be correctly determined on the decoding side. Hence, in the proposed method, even if the block size is set to 2×2, we still can achieve the low ERs with high PSNR values. For the second problem existing in Wang's method, DE (or HS) is incorporated into the proposed method so as to further decrease the embedding distortions.

2. The related methods

2.1. Wang's method

The integer transform defined in Eq. (3) of the paper [7] is listed in Eq. (1).

$$
\begin{aligned}
y_1 &= 2x_1 - a(\mathbf{x}) \\
y_2 &= 2x_2 - 2f(a(\mathbf{x})) + w_1 \\
&= 2x_2 - (a(\mathbf{x}) + LSB(a(\mathbf{x}))) + w_1 \\
&\cdots \\
y_n &= 2x_n - 2f(a(\mathbf{x})) + w_{n-1} \\
&= 2x_n - (a(\mathbf{x}) + LSB(a(\mathbf{x}))) + w_{n-1}
\end{aligned} \tag{1}
$$

where $\mathbf{x} = (x_1, \ldots, x_n) \in \mathbb{Z}^n$ and $\mathbf{y} = (y_1, \ldots, y_n) \in \mathbb{Z}^n$ respectively represent a n-sized pixel array and its corresponding watermarked one, $\bar{\mathbf{x}} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $a(\mathbf{x}) = \begin{cases} \lfloor \bar{\mathbf{x}} \rfloor & \text{if } \bar{\mathbf{x}} - \lfloor \bar{\mathbf{x}} \rfloor < 0.5 \\ \lceil \bar{\mathbf{x}} \rceil & \text{otherwise} \end{cases}$, $f(\mathbf{x}) = \lceil \frac{\mathbf{x}}{2} \rceil$, and w_i ($i \in \{0, 1, \ldots, n-1\}$) denotes 1-bit watermark and $w_i \in \{0,1\}$, and $LSB(\cdot)$ represents the least significant bit (LSB). $a(\mathbf{x})$ is actually the rounded value of $\bar{\mathbf{x}}$.

As can be seen from Eq. (1), Wang's transform can be considered as a prediction process, in which $a(\mathbf{x})$ is used to predict each pixel in this block. The experimental results in [7] show that when the original image is divided into 4×4-sized blocks, the performance is the best. However, refer to Figs. 2 and 3 of the paper [7], Wang are incapable of achieving high PSNR values at the given ERs. This is due to that the larger the block size, the weaker the intra-block correlation. This is to say, 4×4-sized blocks are unable to provide the same intra-block correlations as 2×2-sized blocks. However, when the block size is set to 2×2, the location map cannot be high-efficiently compressed, and thus all the available capacity is almost consumed by the compressed location map. So, Wang can only select 4×4 block so as to increase the compression ratio and achieve the required ERs. However, Wang cannot obtain high PSNR due to low intra-block correlation. Besides, to ensure reversibility, Wang's transform cannot modify flexibly each pixel in a block according to the different difference value between each pixel and the mean value of a block.

2.2. Alattar's transform

Alattar's transform in [6] can be summarized in Eq. (3).

$$
\begin{aligned}
y_1 &= \lfloor \bar{\mathbf{x}} \rfloor - \left\lfloor \frac{2(x_2 - x_1) + w_1 + \cdots + 2(x_n - x_1) + w_{n-1}}{n} \right\rfloor \\
&= \lfloor \bar{\mathbf{x}} \rfloor - \left\lfloor \frac{2\sum_{i=1}^{n} x_i + \sum_{i=1}^{n-1} w_i - 2nx_1}{n} \right\rfloor \\
y_2 &= y_1 + 2(x_2 - x_1) + w_1 \\
&\cdots \\
y_n &= y_1 + 2(x_n - x_1) + w_{n-1}
\end{aligned} \tag{2}
$$

Suppose $k_2 = \sum_{i=1}^{n} x_i - n\lfloor \bar{\mathbf{x}} \rfloor$, and then $k_2 \in \{0, \ldots, n-1\}$. Substitute $\sum_{i=1}^{n} x_i = k_2 + n\lfloor \bar{\mathbf{x}} \rfloor$ into Eq. (2), we have

$$
\begin{aligned}
y_1 &= \lfloor \bar{\mathbf{x}} \rfloor + 2(x_1 - \lfloor \bar{\mathbf{x}} \rfloor) - \left\lfloor \frac{2k_2 + \sum_{i=1}^{n-1} w_i}{n} \right\rfloor \\
y_2 &= \lfloor \bar{\mathbf{x}} \rfloor + 2(x_2 - \lfloor \bar{\mathbf{x}} \rfloor) + w_1 - \left\lfloor \frac{2k_2 + \sum_{i=1}^{n-1} w_i}{n} \right\rfloor \\
&\cdots \\
y_n &= \lfloor \bar{\mathbf{x}} \rfloor + 2(x_n - \lfloor \bar{\mathbf{x}} \rfloor) + w_{n-1} - \left\lfloor \frac{2k_2 + \sum_{i=1}^{n-1} w_i}{n} \right\rfloor
\end{aligned} \tag{3}
$$

where $\lfloor a \rfloor$ rounds a to the nearest integers less than or equal to a, $\sum_{i=1}^{n-1} w_i \in \{0, \ldots, n-1\}$.

As is illustrated in Eq. (3), Alattar's transform can be deemed to contain an additional term and a process which uses $\lfloor \bar{\mathbf{x}} \rfloor$ to predict each pixel in the block. Specially, for each y_i ($i \in \{0, 1, \ldots, n\}$) in