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A Novel Reversible Data Hiding Scheme using IWT with Reduced and Fixed Book keeping Information

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Abstract: In this paper we propose a novel reversible data hiding scheme based on integerwavelet transform. The existing similar schemes contains a significant and variablesize of bookkeeping information leading to reduction in the actual payload capacity ofthe cover image, as well as significant amount of pre-processing is generally requiredto avoid underflow/overflow errors. The proposed scheme tries to resolve the statedproblems and contains a fixed and negligible size of bookkeeping information in theform of location map, as well as there is no pre-processing stage required in theproposed scheme to avoid underflow/overflow problem. Scheme also achievesrelatively higher payload and corresponding PSNR.

Keywords: Reversible data hiding; integer wavelet transform; difference expansion; steganography.

I. INTRODUCTION

OVER the past few years, the enormous increase in theuse of digital content has increased the issues such as online data vulnerability and copyrights violation. One ofthe prominent solutions is the watermarking of the digital content. Besides watermarking, there exists anotherinteresting method that can also provide protection to the digital content, i.e., steganography.

Steganography conceals the very existence of secret information. If theexistence of secret information is revealed, steganography fails. In some applications, even the slightest distortion in the cover work is intolerable. For example, in the field of medical imagery, if a medical image is modified using conventional watermarking, the small changemay affect the interpretation significantly and a physician may make a wrong diagnosis. Similarly, in case of military application, changes due to embedding of secretinformation can substantially alter the cover image andtherefore, the decision taken may cost considerably. Con-sequently, there is a strong need to restore the cover workto its original form. Reversible data hiding (RDH) allowsfull extraction of the embedded information along with the complete restoration of the cover work. RDH is gaining more attention for the last few years because of its increasing applications in military communication, health-care, and law-enforcement. Figure 1 shows the block diagram of a basic RDH scheme.

The existing RDH schemesare mostly fragile in nature. The two important properties of RDH are imperceptibility and embedding capacity. Roughly speaking, imperceptibility is the measure ofsimilarity between stego image (resultant image in whichsecret data is embedded) and the cover image (originalimage). Embedding capacity is the measure of the maximum number of information bits that can be embeddedin the cover image. The performance of a RDH techniqueis thus evaluated on the basis of these measures.

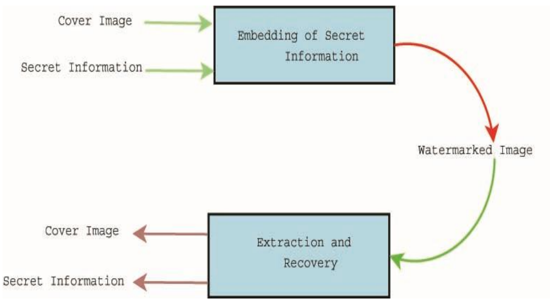

Fig. 1: Standard Reversible Data Hiding Scheme

Generally in most of the RDH scheme there is a significant amount of overhead in the form of book keepinginformation. Book-keeping information consists of location map and underflow/overflow related data. This isconsidered as an overhead and it leads to reduction in the actual payload. In this paper we propose a novel RDH scheme which achieves higher embedding capacity as well as very good PSNR around the achieved pay-load in comparison to previous existing schemes. Our algorithm contains a negligible size of bookkeeping in-formation in the form of location map unlike other similar schemes. There is no requirement of significant pre-processing to avoid underflow/overflow errors as well as storing some metadata for the same. Threshold can also be genuinely selected as per the payload requirements. Current results are without any selection of threshold. The added advantage of our proposed scheme is that the size of the location map is fixed whereas in most of the reversible data hiding schemes the size is variable.

The rest of this paper is organized as follows. Some of the related works around this field is presented in Section 2. Basic difference expansion scheme is explained in Section 3. Then we present our proposed scheme in detail in Section 4. Experimental results are presented inSection 5 followed by conclusion.

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II. RELATED WORKS

Many existing data hiding algorithms are reversible or lossless (e.g., [13, 32, 14]). Typical embedding strategies include lossless compression in [13], difference expansion (DE) in [14], and histogram modification in [32]. Several improved DE based watermarking schemes were then proposed over the time [24, 26, 27]. Most of DE-based reversible data hiding algorithms (e.g.: [14, 7, 8, 1, 23]) prefer choosing small pixel pair differences for embedding. For example, [14] first selected the low-frequency coefficients of integer Haar wavelet transform (i.e., image pixel-pair differences) with small magnitude for DE expansion embedding. [1] extended [14]'s pixel-pair difference expansion method using difference expansion of vectors. Kamstra et al. [23] improved [14] and selected embeddable differences using a sorting list based on the characteristics of the low-pass image. Small differences tend to occur at the beginning of the sorting list. In addition to the methods developed in integer Haar wavelet transform domain, some researchers also proposed DE expansion methods in other domains. For example, to better use the correlation information of neighbouring pixels, [7] used image prediction rather than integer Haar wavelet transform. They still gave priority to small predicted pixel errors for DE expansion embedding. Thodi et al. further proposed a histogram-based selection scheme for choosing small differences in [8]. The reason of giving priority to small differences for DE expansion embedding is to acquire a high peak-signal-to-noise ratio (PSNR) value of the embedded image. In the aforementioned algorithms, PSNR is used as a metric to evaluate visual quality of water- marked images. Few methods of reversible data hiding utilizing prediction error are reported in literature [4, 19, 20, 25, 29, 31]

Kamran et al. [17] improved the work reported by Gao et al. [9] by proposing the embedding of correct message bit only. Due to this improvement, BCH coding and permutation scheme is not required which increases the watermark embedding capacity. Kamran et al. [17] also reported a novel approach which utilizes the concept of down sampling for performance improvement. An et al. [2] presented a semi-blind robust reversible watermarking scheme, which utilizes statistical quantity histogram shifting for embedding, and the extraction procedure is modeled as a classification problem in integer wavelet domain. Some of the recent research in the field of histogram modification based reversible data hiding can be found in [17, 22, 21]. Some robust semi-blind reversible data hiding techniques employing statistical quantity histogram are also reported in literature [2, 18, 10]. Xuan et al in [11] losslessly compresses one or more than one middle bit-planes to save space for data embedding. The bookkeeping data are also embedded as overhead. Another [12] applies threshold embedding technique to embed data in high frequency IWT coefficients. Lin et al. [3] presented a high-performance reversible data hiding technique based on the block difference histogram of a host image. A delicate lossless data hiding algorithm was proposed by [16]. Zeng et al. [30] used adjacent pixeldifference andmulti-layer embedding techniques on a scan path to obtain a reversible watermarking technique. [5, 6] utilized the coefficient-bias algorithm to propose the technique ofcombinational reversible watermarking in both spatialand frequency domains.

III. DIFFERENCE EXPANSION

The DE embedding technique involves pairing the pixels of the host image I and transforming them into a low-pass image L containing the integer averages l and a high-pass image H containing the pixel differences h. If a and b be the intensity values of a pixel-pair, then l and h are defined as

$$l = \frac{a+b}{2} \quad (1)$$

$$h = a - b \quad (2)$$

This transformation is invertible, so that the gray levelsa and b can be computed from l and h

$$a = l + \left\lfloor \frac{h+1}{2} \right\rfloor \quad (3)$$

$$b = l - \frac{h}{2} \quad (4)$$

An information bit i is embedded by appending it to the LSB of the difference h, thus creating a new LSB. The watermarked difference is

$$h_w = 2h + i \quad (5)$$

The resulting pixel gray-levels are calculated from the difference h_w and integer average (l) using (3) and (4).For an image with n-bit pixel representation, the graylevels satisfy $a,b\varepsilon$ [0, 2^n-1], if and only if h and $l$satisfy the following condition:

$$|h| \in R_d(l) = [0, \min(2(2^n - 1 - l), 2l + 1)] \quad (6)$$

where$R_d(l)$ is called the invertible region. Combining (5) and (6), we obtain the condition for a difference to undergo DE.

$$|2h + i| \in R_d \quad (7)$$

This condition is called the expandability condition forDE. A difference that satisfies the expandability condition, given a corresponding integer average, is called an expandable difference.

Apart from the DE embedding technique, Tian's algorithm also uses an embedding technique called LSB replacement. In the LSB-replacement embedding technique, the LSB of the difference is replaced with an informationbit. This is a lossy embedding technique since the trueLSB is overwritten in the embedding process. However,in Tian's scheme, the true LSBs of the differences that areembedded by LSB replacement are saved and embeddedwith the payload, to ensure lossless reconstruction.

The LSB of a difference can be flipped without affecting its ability to invert back to the pixel domain if and only if

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$$\left|2\left[\frac{h}{2}\right]+i\right| \in R_d(l) for\ i=0,1 \quad (8)$$

This is called the changeability condition. A difference satisfying the changeability condition, given a corresponding integer average, is called a changeable difference. An expandable difference is also a changeable difference. A changeable location remains changeable even after its LSB is replaced, whereas an expandable location may not be expandable after DE, but it remains changeable.

IV. PROPOSED SCHEME

We use the sub-bands after applying one level of the DWT only. After using Eqs. (1) and (2) to compute the average and the difference values, the resultant sub-bands represent the average values (LL1), averages of differences (HL1), differences of averages (LH1), and differences of differences (HH1). As a result, the embedding process is achieved by expanding the differences in HL1 and LH1 once and by expanding the difference in HH1 twice. The bits of payload are embedded in the HL1, LH1, and HH1 sub-bands using the following equations:

$$h' = h\,X\,2 + i \quad for\ LH1\ and\ HL1 \quad (9)$$
$$h' = h\,X\,4 + i_2 i_1 \quad for\ HH1 \quad (10)$$

where*i*, i_1 and i_2 are data bits. Thus, 16 data bits areembedded in each expandable block of4×4 pixels.

A. Embedding Process

For an $n \times n$ image, the embedding process is performed in the following steps:

1. The image is divided into non-overlapped blocks of 4×4pixels.

2. The image blocks are scanned sequentially, and each block is transformed using the 1st level Haar DWT presented above. If the block can be embedded without causing overflow or underflow, it is said to be expandable, otherwise it is said to be non-expandable. An embedding map of size $\frac{n}{4} \times \frac{n}{4}$ is generated.

3. Using the resultant map, the expandable blocks are embedded with 16 bits of payload each. The inverse Haar DWT is applied for each block after embedding.

4. The embedding map is embedded into the first four pixels of each block using the original DE technique of Tian as explained in Figure 2.

B. Extraction Process

The steps involved in the extraction process are as follows:

1. The watermarked image is divided into non-overlapped blocks of 4×4 pixels. The first four pixels of each block are scanned and the embedding map is extracted using the original DE.

2. Using the extracted map, the expandable blocks are identified and scanned. For each expandable block, the 1st level Haar DWT is applied, and data bits are extracted from the LSBs of coefficients. The original coefficient's values are recovered using the following equations

$$h = \frac{h'}{2} \text{ for LH1 and HL1} \quad (12)$$

3. The inverse Haar DWT is applied to each expandable block and the original image is recovered completely.

V. EXPERIMENTAL RESULTS

We tested our algorithm on different gray level images shown in Figure 3.

The resultant embedded images are shown in Figure 4.

Experimental results are given in Table 1. According toTable 1 it is very clear that our algorithm has higher embedding capacity as well as very good PSNR around the achieved payload in comparison to previous existingschemes.

PSNR (peak signal-to-noise-ratio) is measurement of the visual quality of the embedded image I_w in comparisonto the original image I:

$$\mathrm{PSNR} = 10.\log_{10}\frac{\mathrm{MAX}_I^2}{\mathrm{MSE}(I, I_W)} \text{ for LH1 AND HL1} \quad (13)$$

whereMAX_I represents the maximum possible pixelvalue of the image. When the pixels are represented using8 bits per pixel, this is 255. Mean squared error (MSE)is given as

$$\mathrm{MSE}\,(I, I_W) = \frac{1}{nXn}\sum_{u=1}^{n}\sum_{v=1}^{n}[I(u,v) - I_w(u,v)]^2 \quad (14)$$

A comparison of the maximum available capacity of theproposed scheme and the schemes in [14] is shown inTable 2.Our algorithm does not require a location map of significant size as well as other book keeping information,which are generally present as overhead in most of theexisting schemes. Threshold can also be genuinely selected as per the payload requirements. Current resultsare without any selection of threshold. The added advantage of our proposed scheme is that the size of the location map is fixed whereas in most of the reversibledata hiding schemes the size is variable.

TABLE I
PAYLOAD VS. PSNR FOR VARIOUS IMAGES

Images	Payload (bpp)	PSNR (dB)
Lena	0.999	31.00
Jetplane	0.990	32.11
Peppers	0.983	30.20
Cameraman	0.907	30.33
Lake	0.983	30.05
Pirate	0.988	31.23
Walkbridge	0.932	29.20
Tiffany	0.959	30.83
Woman	0.997	36.07
Mandril	0.980	28.13

VI. CONCLUSION

In this paper, we have proposed a new algorithm for reversible data hiding. Unlike the previous schemes which contains a significant and variable size of book-

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keepinginformation as an overhead, our proposed scheme has a fixed and negligible size of bookkeeping information inthe form of location map. There is also no metadata orpre-processing involved to avoid underflow/overflow errors in our scheme. By the help of threshold the required payload can be achieved.

TABLE III
A COMPARISON BETWEEN THE PROPOSED AND TIAN'S [14] SCHEME IN TERMS OF MAXIMUM AVAILABLE CAPACITY

Images	Tian [14]	Proposed
Lena	0.500	0.999
Jetplane	0.500	0.990
Peppers	0.500	0.983
Cameraman	0.500	0.907
Lake	0.499	0.965
Pirate	0.500	0.988
Walkbridge	0.499	0.932
Tiffany	0.498	0.959
Woman	0.499	0.997
Mandril	0.500	0.980

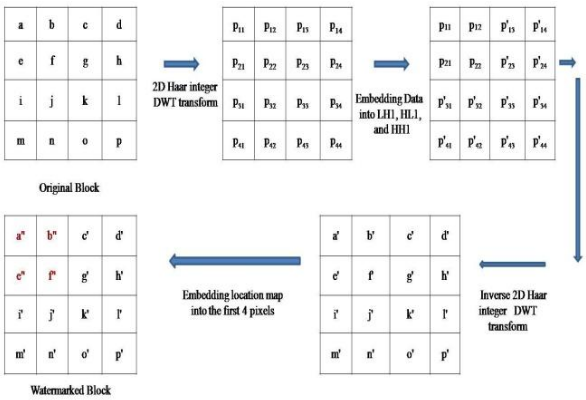

Fig. 2Embedding Process

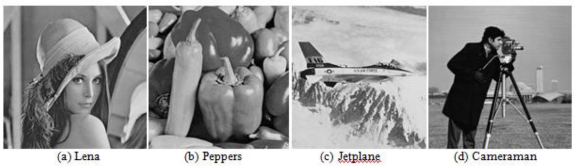

Fig. 3 Standard Test Images (Continued)

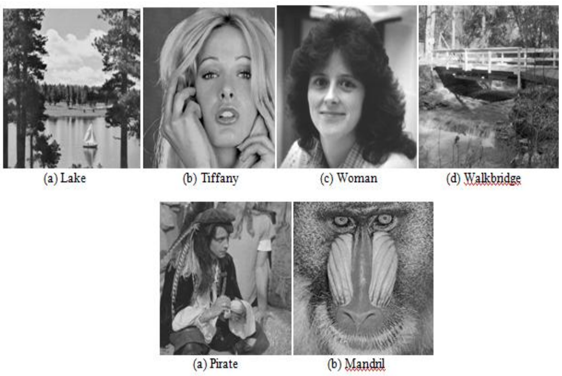

Fig. 3 Standard Test Images

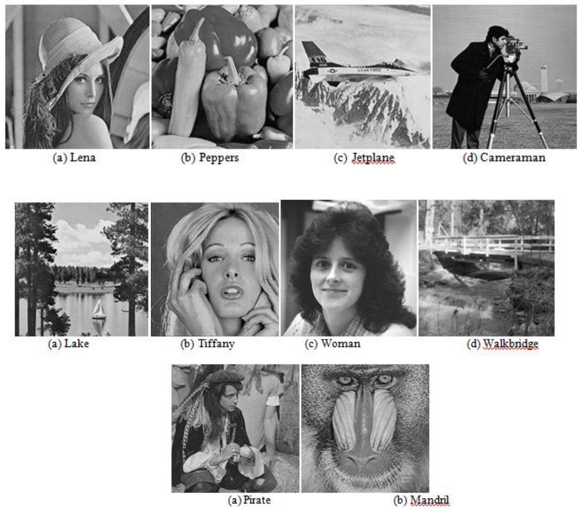

Fig. 4.Embedded Images

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BIOGRAPHIES

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