ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization) Vol.2, Special Issue 1, March 2014

Proceedings of International Conference On Global Innovations In Computing Technology (ICGICT'14)

Organized by

Department of CSE, JayShriram Group of Institutions, Tirupur, Tamilnadu, India on 6th & 7th March 2014

Modified Difference-Histogram based Reversible Data Hiding Scheme

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ABSTRACT: A Reversible Data Hiding (RDH) is a technique which can retrieve both the cover image and hidden data without any distortion from the watermarked image. In this paper, a new reversible data hiding scheme is proposed based on two-dimensional difference histogram modification by using difference-pair-mapping (DPM). DPM is a new technique and it is an injective mapping defined on difference-pairs. This technique is a natural extension of expansion embedding and shifting techniques. By using this technique, the image redundancy can be better exploited by DPM and an improved embedding performance is achieved. In addition with DPM, a pixel-pair-selection strategy is also adopted to priorly used pixel-pairs located in smooth image regions to embed data. This leads to further enhancement in the embedding performance.

KEYWORDS: Difference-pair-mapping (DPM), histogram modification, reversible data hiding (RDH), two-dimensional difference-histogram

I. INTRODUCTION

Reversible data concealing is a data hiding scheme which is widely used for covert communication. In this technique, the secret information is concealed into a cover media by slightly modifying its pixel values and the embedded message as well as the original cover image should be completely recovered from the watermarked image [1]. RDH is a special type of information hiding and its feasibility is mainly due to the lossless compressibility of natural images. The reversibility in RDH is quite desirable and helpful in some practical applications such as medical image processing [2], multimedia archive management, image trans-coding, and video error-concealment coding, etc. Generally, the performance of a RDH scheme is assessed by the behaviour of capacity-distortion. For a required embedding capacity (EC), to obtain a good marked image quality, one expects to reduce the embedding distortion as much as possible. Many RDH methods have been proposed so far, e.g., the methods based on lossless compression, difference expansion [4], histogram modification [5], [6], prediction-error expansion [9], and integer transform, etc. Among these methods, the histogram-based methods are widely used. The histogram-based methods modify the histogram in such a way that certain bins are shifted to create vacant space while some other bins are utilized to carry data by filling the vacant space. This type of methods can well control the embedding distortion and provide a sufficient EC. The first histogram-based RDH method is the one proposed by Ni *et al.* in [16]. This method uses peak and minimum points of the pixel-intensity-histogram to embed data. It changes each pixel value at most by 1, and thus a good marked image quality can be obtained. However, its EC is quite low and this method does not work well if the cover image has a flat histogram. To alleviate it, Lee *et al.* [5] proposed to utilize the difference-histogram instead. This novel method exploits the correlation among neighbouring pixels and can embed larger payload with reduced distortion compared with Ni *et al.*'s. Moreover, Lee *et al.*'s method works by modifying the two-dimensional pixel-intensity-histogram by using pixel-pair-mapping (PPM). The PPM is a mapping technique which is an injective mapping defined on pixel-pair. Afterwards, Fallahpour [6] introduced a method by modifying the histogram of prediction-error. Except these aforementioned methods, many other works are also based on histogram by incorporating some strategies such as double-layered embedding [10], [11], embedding-position-selection [9], [10], [12], adaptive embedding [9], context-modification [22], etc.

The histogram-based RDH methods generally contain two basic steps:

- Histogram generation
- Histogram modification

In the first step, correlation of the local image is simplified to a one-dimensional statistic. Clearly, by this simplification, the redundancy of the image cannot be fully exploited and it only contributes to the second step since a one-dimensional histogram is easy to deal with. Based on this consideration, instead of one-dimensional histogram used in previous RDH methods and to better exploit the image redundancy, a novel Reversible Data Concealing scheme by using a two-dimensional difference-histogram is used. For the proposed method, by considering a pixel-pair and its context, a local image region is projected to a two-dimensional space to obtain a sequence consisting of difference-pairs. Then, a two-dimensional difference-histogram is generated by counting the difference-pairs. Finally, reversible data embedding is implemented according to a specifically designed difference-pair-mapping (DPM). Here, the DPM is an injective mapping defined on difference-pairs, and it is a natural extension of expansion embedding and shifting techniques used in current histogram-based methods.

By using the two-dimensional difference-histogram and this specific DPM, compared with the conventional one-dimensional histogram based methods, more pixels are used for carrying data while the number of shifted pixels is reduced as well, and thus an improved embedding performance is achieved. In addition, inspired by the embedding-position selection techniques introduced in previous works [9], a pixel-pair-selection strategy is adopted in the proposed method to priorly use the pixel-pairs located in smooth image regions to embed data. This may further enhance the embedding performance.

II. PROPOSED RDH SCHEME

The proposed RDH scheme is based on modification of two-dimensional difference-histogram by constructing a DPM which is an injective mapping defined on difference-pairs. This Section consists of the detailed description of the proposed system and its evaluation and data embedding and data extraction procedure.

A. DPM for RDH

For a pixel-pair (x, y), compute two difference values $d_1 = x - y$ and $d_2 = y - z$ to form a two-dimensional difference-histogram of (d_1, d2), where z is a prediction of y. The pixel-pair (x,y) has four choices: $(x-1,y)$, $(x+1,y)$, $(x,y-1)$, or (x,y+1) (see Fig. 1(a)). Based on these four modification directions, Lee *et al.*'s method can be improved by designing a new PPM.

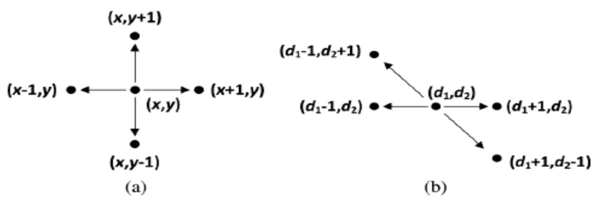

Fig. 1 (a) By modifying either x or y by 1, (x, y) has four modification directions. (b) The corresponding difference-pair (d_1 , d_2) also has four modification, where $d_1 = x - y$, $d_2 = y - z$, and is a prediction of y.

Inspired by the aforementioned new PPM, either x or y is modified by 1. In the PPM, since (x, y) has four modification directions, the difference-pair also has four modification directions: $(d_1 - 1, d_2)$, $(d_1 + 1, d_2)$, $(d_1 + 1, d_2 - 1)$ or $(d_1 - 1, d_2 - 1)$, given in fig. 1(a) and 1(b). For example, by modifying to, the modification direction to (x , y) is "up" and the corresponding modification direction to (d_1, d_2) is "upper-left", since d_1 changes to $d_1 - 1$ and d_2 changes to $d_2 + 1$. Based on these four modification directions, a new RDH scheme by designing a DPM is introduced. The idea of two-dimensional pixel-intensity-histogram of Lee *et al.*, is extended to two-dimensional difference-histogram. Besides, for each (x, y), compute the predication of y based on the context of (x, y) for an accurate estimation. Here, the gradient-adjusted-prediction (GAP) will be used in this scheme. Moreover, to further improve the marked image quality, a strategy to select smooth pixel-pairs is adopted for data embedding. The main idea of this strategy is similar to those of pixel selection of the previous work [9] and error energy estimation of Hong [12]. By pixel-pair-selection, a noisy-level is computed for each pixel-pair, and only the pixel-pairs with relatively small noisy-levels will be embedded.

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	j	*j*+1	*j*+2	*j*+3
i	x	y	v_1	v_2
i+1	v_3	v_4	v_5	v_6
i+2	v_7	v_8	v_9	v_{10}

Fig. 2. Context of (x, y), where the location of pixel x is (i, j) . The blue pixels are used to compute the GAP predictor for y, and all ten pixels $\{v_1,\ldots,v_{10}\}$ are used to compute the noisy-level.

The brief introduction of the embedding procedure is given below. First, divide the cover image into nonoverlapped pixel-pairs. For each pixel-pair *(x, y)*, compute the prediction of to get using GAP predictor:

$$z = \begin{cases} v_1, & \text{if } d_v - d_h > 80 \\ \frac{(v_1+u)}{2}, & \text{if } d_v - d_h \in (32, 80) \\ \frac{(v_1+3u)}{4}, & \text{if } d_v - d_h \in (8, 32) \\ u, & \text{if } d_v - d_h \in (-8, 8) \\ \frac{(v_4+3u)}{4}, & \text{if } d_v - d_h \in (-32, 8) \\ \frac{(v_1+u)}{2}, & \text{if } d_v - d_h \in (-80, -32) \\ v_4, & \text{if } d_v - d_h < -80 \end{cases} \quad (1)$$

Where $\{v_1,\ldots v_7,v_8\}$ are neighbouring pixels of *(x, y)* (see Fig. 2), $d_v = |v_1 - v_5| + |v_3 - v_7| + |v_4 - v_8|$ and $d_h = |v_1 - v_2| + |v_3 - v_4| + |v_4 - v_5|$ represent the vertical and horizontal gradients, and $u = (v_1 + v_4)/2 + (v_3 - v_5)/4$. Notice that z should be rounded to its nearest integer if it is not an integer. Then, compute the noisy-level of *(x, y)* denoted as using its ten neighbouring pixels (see also Fig. 2) as *NL(x, y)* using its ten neighbouring pixels $\{v_1,\ldots,v_{10}\}$ as

$$NL(x,y) = \int_{(i',j')\in v} |\nabla I(i', j')| \quad (2)$$

where V represents the context of containing the ten pixels and ∇ stands for the gradient operator. Here, for discrete image, the noisy-level is computed by summing both vertical and horizontal differences of every two consecutive pixels in V, and it is less than or equal to 13 x 255 = 3315.Clearly, a pixel-pair located in smooth regions may have a small noisy-level. Finally, for each pixel-pair with noisy-level less than a threshold *T*, compute the difference-pair (d_1, d_2), and implement data embedding.

Each black point in this DPM is mapped to a blue one and it will be used for carrying one data bit, while each blue point is mapped to another blue one and it is simply shifted to ensure the reversibility. Any DPM can give a RDH scheme if it is an injection. As for the DPM shown in Fig. 4, the idea is to use as much as possible the points with high frequency to carry data. So some points (d_1, d_2) are taken with either d_1 or d_2 small as black to carry data, and meanwhile the other points are shifted according to the four allowable modification directions. The superiority of this specific DPM will be experimentally demonstrated in the next subsection. Some explanations are given for the final step of proposed method to clarify how DPM works. For example, when *(x, y)* = (132, 132) and z = 131, the corresponding difference-pair is (d_1, d_2) = (0, 1) which is a black point in figure 4. In this case, the pixel- pair will be expanded to carry one data bit:

1. if the to-be-embedded data bit b=0, the marked pixel-pair is taken as *(x,y)* itself.
2. if the to-be-embedded data bit b=1, the marked difference pixel-pair is then taken as its associate point(-1,2) where the modification direction is “upper-left”, and thus the marked pixel-pair is taken as the upper neighbor of *(x,y)*, i.e., (x,y+1) = (132, 133).

For another example, *(x, y)* = (132,132) and *z*, the difference-pair is (d_1, d_2) = (1, -2) which is blue. In this situation, the pixel-pair will be shifted. Since the modification direction to this difference-pair is “lower-right”, the marked pixel-pair is then taken as the lower neighbour of *(x, y)* i.e., (*x, y*-1) = (132,130). For general cases, as a detailed description of the DPM shown in Fig. 4, the marked value is listed in Table I. Notice that the pixel-pair scanning order in data extraction procedure is inverse to that of embedding. By this means, when processing a pixel-pair in data extraction, its

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ISSN (Print): 2320-9798

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context has already been recovered. Thus the same prediction and noisy level used by encoder can be obtained by decoder. This issue and the injectivity of DPM guarantee the reversibility of the proposed scheme. The difference values $d_1^m = x^m - y^m$ and $d_2^m = x^m - z$ are computed from the marked pixel-pair (x^m, y^m), where z is the same prediction used in data embedding by encoder.

B. Evaluation for DPM

For the histogram-based RDH, if the maximum modification to pixel values is 1 in data embedding, the expected value of the modification (in - l^2 norm) to cover image is $\frac{N_{exp}}{2} + N_{shift}$, where N_{exp} and N_{shift} are numbers of expanded and shifted pixels, respectively.

TABLE I
MARKED VALUE OF COVER PIXEL-PAIR (x, y) ACCORDING TO THE DPM

Condition on (d_1, d_2)	**Operation in data embedding**	**Modification direction to the difference-pair**	**Modification direction to the pixel-pair**	**Marked value**
$d_1 = 1$ and $d_2 > 0$	expansion embedding	right	right	$(x + b, y)$
$d_1 = -1$ and $d_2 < 0$	expansion embedding	left	left	$(x - b, y)$
$d_1 = 0$ and $d_2 \geq 0$ $d_1 < 0$ and $d_2 = 0$	expansion embedding	upper-left	up	$(x, y + b)$
$d_1 = 0$ and $d_2 < 0$ $d_1 > 0$ and $d_2 = 0$ $d_1 = 1$ and $d_2 = -1$	expansion embedding	lower-right	down	$(x, y - b)$
$d_1 > 1$ and $d_2 > 0$	shifting	right	right	$(x + 1, y)$
$d_1 < -1$ and $d_2 < 0$	shifting	left	left	$(x - 1, y)$
$d_1 < 0$ and $d_2 > 0$	shifting	upper-left	up	$(x, y + 1)$
$d_1 > 1$ and $d_2 < 0$ $d_1 = 1$ and $d_2 < -1$	shifting	lower-right	down	$(x, y - 1)$

Thus the ratio of expanded pixels

$$\frac{N_{exp} + N_{shift}}{2} \tag{3}$$

is a measurement of the embedding performance.
The larger the ratio is, the less modification to cover image and better performance is. Then (3) is used to demonstrate the superiority of the proposed DPM- based scheme. For the proposed method, when the pixel-pair-selection threshold T is taken as its maximum, i.e., the sum of maximum noisy-level of all pixel-pairs and 1

$$1+\max_{(x,y)} NL(x, y) \tag{4}$$

it means that the pixel-pair-selection strategy is disabled and all pixel-pairs are used for data embedding.

The proposed method is better than those prior arts since it always has a larger ratio and the performance comparison of the proposed method with previous methods is shown in figure 3. The superiority of the two-dimensional difference-histogram and this specifically designed DPM is thus verified. On the other hand, the ration becomes larger with smaller T. This demonstrates the advantage of pixel-pair-selection strategy.

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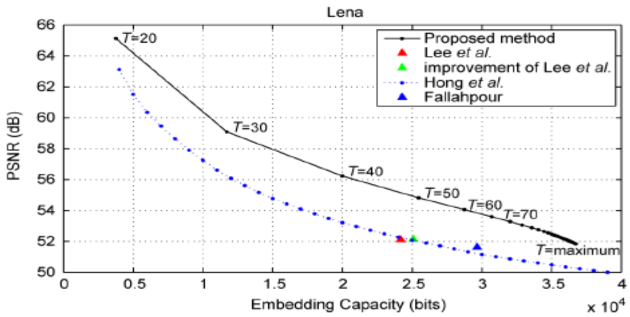

Fig. 3. Performance comparisons between the proposed method, Lee *et al.*'s method [5] and its improved one, Hong *et al.*'s MED-based method [7], and Fallahpour's GAP-based method [6], for image Lena.

C. Block diagrams for embedding and extraction procedures

The proposed data embedding procedure contains several basic steps. First, divide the cover image into nonoverlapping pixel-pairs. Then, embed the secret message into a part of cover image (noted as I'). Next, record the least significant bits (LSB) of some pixels of (noted as I'') to get a binary sequence, and embed this sequence into the rest part of *I*, i.e., $I - I'$. Finally, by using LSB replacement, embed the auxiliary information and the compressed location map into I''. The overflow location map is used to overcome the overflow and underflow problems. The compression of location map is achieved by arithmetic coding. The secret data is embedded by DPM method whereas the auxiliary data is embedded by LSB replacement. In this embedding procedure, the smooth pixel-pairs are used to embed the secret data. This enhances the embedding performance. The data extraction procedure is the reverse process of the data embedding procedure. In data extraction procedure, first the LSB replacement is performed to extract the compressed location map and the location map is generated by decompressing it. Decompression of the location map is done by blind decoding.

The prediction and noisy level are computed according to the equation (1) and (2). The image restoration can be realized by extracting the LSB sequence. The block diagrams of data embedding and data extraction are shown in the figure 4 and 5.

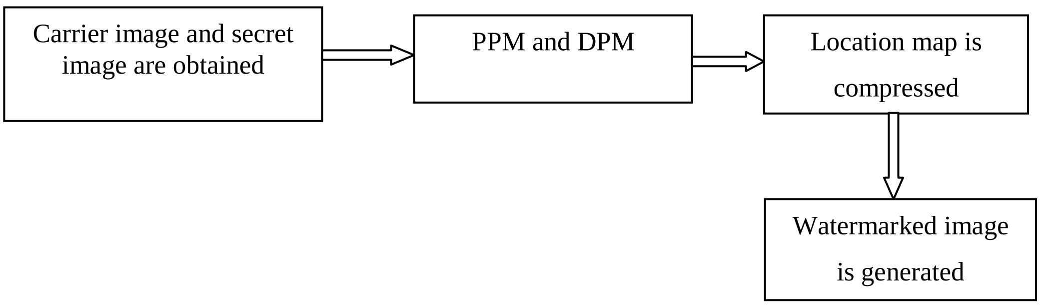

Fig.4. Block diagram for embedding procedure

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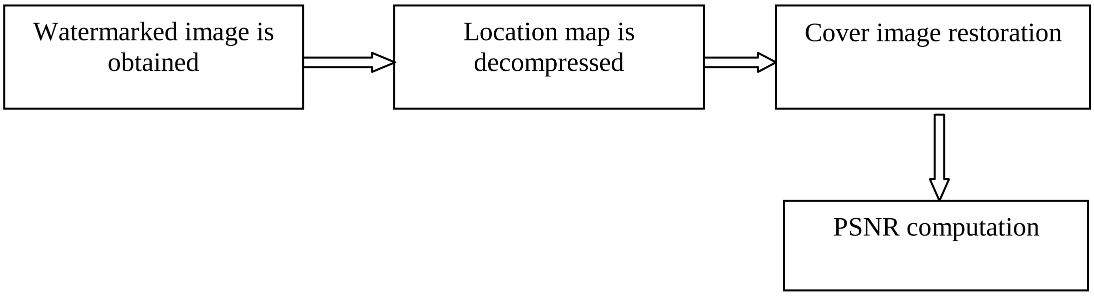

Fig.5. Block diagram for extraction procedure

III.EXPERIMENTAL RESULTS

Six 512X512 sized gray-scale images including Lena, Baboon, Barbara, Airplane (F-16), Peppers, and Fishing boat are used, shown in figure 6. The proposed method is superior to aforementioned methods. It experimentally demonstrates that the DPM-based scheme can provide a much better performance than PPM.

Fig.6. Six test images. From left to right: Lena, Baboon, Barbara, Airplane (F-16), Peppers, and Fishing boat.

Moreover, compared with the methods of Fallahpour and Hong *et al.*, the superiority of the proposed is also significant. The two methods are based on the prediction-error-histogram with different predictors. Although these methods may exploit the spatial redundancy for a larger pixel context and perform better than Lee *et al.*'s in most cases, the scheme can improve them by increasing PSNR by 1–6 dB. The advantage lies in the utilization of two-dimensional difference-histogram and pixel-pair-selection strategy. The performance comparisons of PSNR between the proposed method and other four methods are shown in the Table II.

TABLE II
COMPARISONS OF PSNR (IN DB) BETWEEN PROPOSED METHOD AND FOUR METHODS OF SACHNEV *ET AL.* [10], LI *ET AL.* [9], HONG [12], AND HONG [11], FOR AN EC OF 20,000 BITS (ER = 0.076 BPP)

Image	**[10]**	**[9]**	**[12]**	**[11]**	**Proposed Scheme**
Lena	55.03	54.82	54.92	54.97	56.15
Barbara	55.04	55.29	54.89	55.18	56.24
Airplane(F-16)	57.34	56.84	58.58	59.67	59.45
Peppers	52.30	52.55	52.16	52.20	53.39
Fishing boat	52.65	52.43	52.26	52.37	53.12
Average	**54.47**	**54.39**	**54.56**	**54.68**	**55.67**

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IV. CONCLUSION

In this paper, a novel Reversible Data Concealing scheme by using a two-dimensional difference-histogram according to a specifically designed DPM is presented. The proposed method is employed in a higher dimensional histogram, i.e., one-dimensional difference histogram modification, to design RDH. In DPM method, the one of the pixel in a pixel-pair is modified by 1 in value. By using DPM, the number of pixels carrying data is increased whereas the number of pixels used for shifting is decreased. In addition, a pixel-pair-selection strategy is also adopted in the proposed method to priorly use the pixel-pairs located in smooth image regions to embed data. The smooth image region has less noisy level. This is proposed to further enhance the embedding performance. On compared with the previously introduced one-dimensional histogram based methods, the proposed approach can exploit the image redundancy better and achieve an improved performance.

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