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A Multi-Layered "Plus-Minus one" Reversible Data Embedding Scheme

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Abstract. *Reversible Data Hiding (RDH) is one of the most well-known methods adopted for concealed communication. One of the major issues in RDH is the overflow/underflow which exists in almost all the embedding techniques. This is a major issue which hinders the hiding capacity in many existing techniques. In the proposed novel LSB ODD/EVEN embedding algorithm, neither histogram modification (which involves shifting) nor difference expansion (which involves shifting and expansion of error) techniques are involved. No overflow/underflow problem is reported in the proposed method and involves multilayer embedding. Performance of this approach or any data hiding schemes are usually measured in terms of MSE, PSNR, and SSIM. This approach is tested over standard test images that includes medical images also and compared with well-known existing schemes.*
Keywords: Histogram; ODD/EVEN; Difference expansion; Watermark

1. **Introduction.** Close to two decades, one of the most active areas of research in the research community is data hiding. Data hiding is a mode of concealed communication between the interested parties. Data is hidden into the original image usually called as cover image. The receiver can extract the embedded secret message using the extraction technique. After extracting the secret information, recovering the cover image is of great challenge in reversible data hiding techniques. Previously in data hiding, after extraction of the secret information, original data on which it is embedded is lost. In reversible data hiding secret information as well as the cover image is extracted out of the marked/stego image [1] V [5]. There are a huge number of applications which uses RDH and it has been listed in the literature that includes medical image processing [6] [7], content authentication [8] [9], military image processing, law enforcement, recovery of vector map in Computer-Aided Design (CAD) [10] [11], video error coding [12] [13], etc.. Steganography and Digital Watermarking techniques were least bothered about the cover information after extraction of hidden data. Always Reversible Data Hiding needs to be lossless. In RDH, data is hidden sensibly in its own risk and extraction is also performed wisely by recovering the cover information.

2. **State of ART Review.** More researches have been performed in RDH close to two decades. Initial RDH schemes were focused on lossless compression techniques [14]-[19] which compresses certain characteristics features of the original image and finding out space for embedding. Widely adopted method was Difference Expansion (DE) and Prediction Error Expansion (PEE). Tian [20] introduced DE in which the difference between the neighboring pixels is expanded to make room for embedding. Later, this expansion technique was held in a different way by Thodi and Rodriguez [21] by expanding the prediction error and later widely adopted and improved further by many RDH works. Expansion embedding is the common factor in both techniques. In PEE every image point, z is predicted by means of any one of the adopted prediction techniques such as MED, GAP, sorting, etc. Prediction for z can be computed as an error $(e) = z - z^\wedge$. Later, error (e) is expanded as e^=2e+m wher m $\varepsilon \{0, 1\}$. Coltus [22] method was based on reversible contrast mapping which performs an Integer Transform on integer pair. Weng et al. [23] scheme used two types of Integer Transform of pixel pair by considering its difference value on magnitude. Kamstra and Heijmans [24] improved Tian's method by performing DE and sorting, thus compressing the location map remarkably.

Further, more and more efficient algorithms were proposed that focused on modifying the histogram of the original image which was proposed first by Ni et al. [19]. In histogram modifying approaches [25][26], the peak point in image histogram was modified to embed data onto it. After generating the histogram certain pixels are shifted to create vacant space for embedding. One or more peak point was chosen by dividing the cover image into several non-overlapping blocks to embed more data. Lee [27] proposed a data embedding scheme using histogram modification of difference image.

Later, RDH methods using contrast enhancement was introduced. Contrast enhancement was done by histogram bin expansion [28]. Otsu [29] proposed a method to embed data into medical images using contrast stretching. In that, the image was segmented into the region of interest (ROI) and background. The contrast in the ROI was enhanced selectively.

Encryption is one of the most popular means of privacy protection now a day. RDH is carried out in the encryption domain. There are two methods of RDH in the encryption method. Vacating room before encryption (VRBE) [30] [31] and Vacating room after encryption (VRAE) [32]. Many researches have been carried out for more than ten years in the encrypted domain. In [33]-[35] embedding of data is carried out in plaintext and then securely transmitted to the receiver after encryption. Interpolation is also another branch of RDH technique used in images. In this technique, the original size of the image is scaled down onto which interpolation is performed to get the cover image. The state of art review in interpolation techniques are Neighbor Mean Interpolation (NMI) [36] [37] [38], Interpolation by Neighboring Pixels (INP) [39], Pixel Repetition Technique, etc., Initial interpolation based RDH technique was proposed by Jung and Yoo[37]. They adopted Neighbor Mean Interpolation technique. Further, Abadi et al., [29] that increases the payload by using histogram modification technique, modified Jung and Yoo's method. Lee and Huang [39] proposed a technique called INP, which provides extremely high payload for embedding. RDH in clinical images has been developed by Arsalan et al.,[40] in which the Genetic Algorithm (GA) and compounding techniques have been used. Another technique [41] trades conventional RDH by Reversible Contrast Mapping (RCM), which was introduced by Colcut,'s that gives low computational complexity. Shabir et al.,[42] and Geetha et al., [49-50] suggested an interpolation RDH technique in medical images which employs pixel to block conversion and achieved very high embedding capacity with tampering mechanism. [43] explains about performing I-IWT and pixel pair prediction in medical images.

In this paper, a novel LSB reversible embedding approach, which do not involve any of the previously discussed embedding techniques like modifying the histogram of the image or expanding the neighboring pixel difference or expanding the predicted error or performing any interpolation over the image. The experimental results are compared with well-known existing algorithms like Sachnev et al. [44], Dragoi and Coltuc [45], Li et al [46] Bo Ou et al [47] and Gui et al [48] all that works basically on prediction error expansion technique. Of all, Bo Ou et al[47] is one of the preferred algorithms for low-level embedding rate and at the same time, Gui et al[48] is considered to be one of the well -known schemes for high embedding rates. The proposed scheme is compared with both lower and higher embedding schemes.

3. **Proposed Method.** In the proposed method, to obtain reversibility the status of the pixel pair before each layer of embedding is noted and preserved in the cover image. This vital information is compressed using JBIG2 compression and embedded by means of same ODD/EVEN technique which is used for embedding the data. The altered LSBs while embedding the vital information is embedded along with the payload. Following section describes the theory related to proposed embedding technique:

A. Embedding strategy based on pixel position P_p and pixel value P_v:

A grayscale image can be denoted by the set: {(i,j,I(i,j))} where (i,j) represents the pixel coordinates, $1 \leq i \leq M, 1 \leq j \leq N$, for integers M and N and $I(i,j)$ is the corresponding pixel intensity value (P_v). Let the column index 'j' of the pixel position be denoted as P_p. For a typical grayscale image $0 \leq I(i,j) \leq 255$ when represented in integer or $0 \leq I(i,j) \leq 1$ for a real value representation of the pixel intensity. The proposed RDH scheme primarily considers 3 entities for embedding.

1. Secret message bit (either '0' or '1')
2. P_p(column index 'j' being either 'odd' or 'even')
3. P_v(either 'odd' or 'even'). As an act of embedding the P_v is sustained without any change or is incremented or decremented by a value of 1.

In most of the existing RDH schemes, the auxiliary information is calculated for facilitating the hiding function. In histogram-based methods, the histogram bin with the maximum peak value is identified for possible shifting on both sides to accommodate the secret bits. Similarly, in expansion schemes, the error is estimated and expanded so that the payload can be appropriately hidden. However, in this proposed method, we aim to use a natural and apparently available fact of the image and the secret message, avoiding the calculation of any auxiliary information. One such readily accessible detail is the pixel value, which we check as to whether 'odd' or 'even'. For framing the embedding strategy, another data viz., pixel position P_p is also considered and is checked whether 'odd' or 'even'. No extra computation like shifting or expansion is involved.

A code-book (akin to look-up table) based on these three parameter values (Msg, P_p, P_v) is constructed for embedding, whose logic is discussed below. If the secret bit to be embedded is '1' i.e., Msg='1' and if both $Odd(Pp) = True$ $Odd(Pv) = True$ and, then pixel value is not changed i.e., $Pv_{new} = Pv\_old$. Similarly, if both $Even(Pp) = True$ and $even(Pv) = True$, even then pixel value is not changed., $Pv_{new} = Pv\_old$. If $Odd(Pp) = True$ $Even(Pv) = True$ and, then pixel value is incremented by 1 i.e., $Pv_{new} = Pv_{old} + 1$. If $Even(Pp) = True$ $Odd(Pv) = True$ and, then pixel value is decremented by 1 i.e., $Pv_{new} = Pv_{old} - 1$. If the secret bit to be embedded is '0' i.e., Msg='0' and if bothe $Odd(Pp) = True$ and $Even(Pv) = True$, then pixel value is not changed i.e., $Pv' = Pv$. Similarly, if both $Even(Pp) = True$ and $Odd(Pv) = True$, even then pixel value is not changed. $Pv' = Pv$. If $Odd(Pp) = True$ $Odd(Pv) = True$ and, then pixel value is decremented by 1 i.e., $Pv' = Pv - 1$. If $Even(Pp) = True$ and $Even(Pv) = True$, then pixel value is incremented by 1 i.e., $Pv' = Pv + 1$.

B. Data Embedding Algorithm:

Like all image processing techniques, encoder plays a major role for the decoder, so that the decoding is done using the same data. In the process of embedding data, LSB of the pixels are modified because of embedding procedure and to obtain reversibility. Embedding algorithm consists of various steps. We will discuss the steps involved below:

Let us consider that the cover image I has n elements $\{I_k\}_{k-1}^{n}, I_k \in k$, where K is the range of values for I_k where $K = \{0, 1, 2, ..., 255\}$ From the encoder side cover image is divided into two parts $I = I^0 + I^1$. I^0 is for embedding and I^1 is for carrying the overhead information required for extraction and reversibility. Secondly, the embedding part of the image pixels is paired either by pairing the pixels horizontally on the same row and consecutive columns (k, 2l-1) and (k, 2l) or same column and consecutive row pixels (2k-1, l) and (2k, l) or pattern based pairing. Third, a location map of one-bit bitmap $\mathcal{B}$ is created whose size is equal to the number of pixel pairs in step 2. Value 1 in the location map L indicates that the paired pixels are both odd/even, value 0 indicates either of the paired pixels is odd and the other is even. This one-bit bit-map is losslessly compressed using JBIG2 compression. Compressed location map is embedded as per the embedding procedure given in Table.1. Altered LSBs of the pixels, let it be $\mathbb{Q}$ after compression is embedded along with the payload $\mathbb{P}$.

Total embedding capacity C is $\mathbb{P} + \mathbb{Q}_{(compressed)}$ where $\mathbb{P}$ is the actual payload and $\mathbb{Q}$ is altered LSB required for reversibility.

C. Data Embedding Steps:

INPUT: Grayscale image I with M-rows and N-columns, Secret payload SPin bits of length'W',

OUTPUT: Stego image $\hat{I}$

Procedure

1. Convert the $2D$ image I of dimensionMxN, into an $1D$ array of pixel values I', for easy processing and convenient indexing. Now the pixel position could be denoted using a single index. Thus a $2D$ image of M rows and N columns, i.e., size MxN, will become an $1D$ array of size $1 \times MN$
2. Combine every two consecutive pixels in the first half of I'. Altogether, there will be $\frac{MN}{4}$ pixel pair array.
3. Let each pixel pair be denoted by (x_i, y_i), where i=1,2,...$\frac{MN}{4}$
4. Form a binary array $\mathscr{B}$, by a suitable binary value for each pixel pair in the array.
   S = mod $((x_i, y_i)$,2)
   If $S_{xi} = S_{yi}$ then $\mathscr{B}_i = 0$; else $B_i = 1$;
   Finally, compress $\mathcal{B}$ using JBIG2 compression technique and preserved in the second half of I' to obtain reversibility.
5. In the first round, a single bit can be embedded in each pixel pair (x_i, y_i)
   In each (x_i, y_i) find p_s for both (x_i, y_i) and e_m for x_{i+1}
   $x_{imodified} = x_i$ with LSB replaced by p_s
   $y_{imodified} = y_i$ with LSB replaced by $(p_s \oplus p_s(e_m))$

P_s bit in Table 1. shows that the LSB of the original pixel will get modified if it is '1', remains unchanged if '0'.

Table 1. Embedding Strategy Adopted In This Wor

Secreet Message Msg	Pixel Position (Column index) P_p	Pixel value P_v	Embedding Strategy	Embeddable Message e_m without modifying P_v	Pixel status P_s Modified=1/Not modified=0
0	$Odd(P_p) = True$	$Odd(P_v) = True$	$P'_v = P_v - 1$	1	1
0	$Odd(P_p) = True$	$Even(P_v) = True$	$P'_v = P_v$	0	0
0	$Even(P_p) = True$	$Even(P_v) = True$	$P'_v = P_v + 1$	1	1
0	$Even(P_p) = True$	$Odd(P_v) = True$	$P'_v = P_v$	0	0
1	$Odd(P_p) = True$	$Odd(P_v) = True$	$P'_v = P_v$	1	0
1	$Odd(P_p) = True$	$Even(P_v) = True$	$P'_v = P_v + 1$	0	1
1	$Even(P_p) = True$	$Even(P_v) = True$	$P'_v = P_v$	1	0
1	$Even(P_p) = True$	$Odd(P_v) = True$	$P'_v = P_v - 1$	0	1

The compressed binary array $\mathscr{B}$ is preserved in the LSBs of the image points. Replace LSBs starting from $I_{(M/2+1,1)}$ using the embedding strategy adopted in this work to embed the below mentioned auxiliary information required for reversibility:

- Capacity control factor L (8 bits) states the number of layers of embedding performed on the image.
- $L \times n_{Bt}$ number of bits where n_B is the total number of bits in tth binary array $\mathscr{B}$ (8 bits for each n_{Bi}).
- Followed by binary array $\mathscr{B}_t$ where t=1,2,3...L.

After which the marked image is generated.

JBIG2 codec (international standard for lossless compression of bitmaps) is a well-known image compression standard used for binary images. In lossless mode JBIG2 generates files 2-4 times smaller than JBIG. JBIG2 makes use of MQ coder.

D. Data Extraction steps:

- Decode L starting from $I_{(M/2+1,1)}$ using the reverse embedding strategy adopted in this work to extract the number of levels of embedding performed.
- Extract $L \times n_{Bt}$ number of bits. Each 8 bits represents the total number of bits in tth binary array $\mathscr{B}$
- Extract each binary array sequence $\mathscr{B}_t$ and decompress using JBIG2 decompression technique to get the pixel pair status before tth layer embedding.
- By using the pixel pair status, secret message Msg can be extracted using reverse embedding strategy.
- Modified LSB information embedded along with the payload is also decoded from the extracted data and finally the cover image is recovered.

Fig 1. Shows the sample block of $6x6$ in an image and how it is divided into two portions which is the initial step before starting with the embedding procedure. First half of the image is for embedding in which the pixels are paired and is shown as filled dot. The status of the pairs is represented in array of bits and the compressed format of the bit array is stored in LSBs of the second half of the image which is shown as a hollow dot.

For understanding the embedding procedure, a 4×3 block of pixels from Lena image is considered. Step by step embedding procedure is explained in detail and shown in Figure 2. Pairing of pixels can be done starting from any location. But this information needs

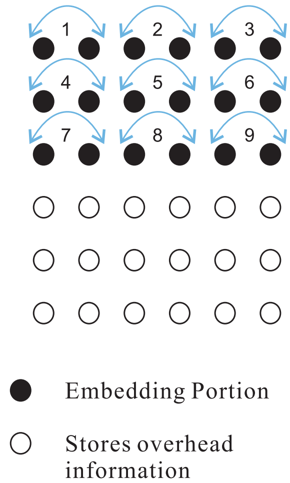


FIGURE 1. Illustrative example of pixel grouping when block size is 6 × 6

to be transmitted to the receiver side by mentioning the start location, direction and end location.

In fig 2 initially the image block is transformed into one dimensional array which is paired subsequently. The bubbled dots in fig 1. imitates pixel pairing. Two facts we need to consider for this embedding approach is:

- According to code-book given in Table 1 what msg bit can be embedded within the pixel pair without modifying them?
- For the given msg bit, will the original pixel LSB will get modified or remains unchanged?

The embedding approach is based on this two information. There is no computational complexity involved in developing this approach. But it remains logically strong enough and more suitable for RDH. Segmenting the image space for embedding and storing the overhead information depends on the amount of payload and the overhead information.

4. **Experimental Analysis.** In this section, we discuss the experimental results of the proposed embedding scheme when performed on various test images. Standard sized 512 x 512 grey scale images are selected as test images and the same is shown in Fig 3. The proposed scheme is compared with four well known existing prediction error expansion techniques like Sachnev et al. [44], Dragoi and Coltuc [45], Li et al [46] Bo Ou et al [47] and Gui et al [48]. We see that the proposed scheme is independent of image characteristics. Comparison is done by mainly looking into the PSNR values of various selected schemes for selected images.

For a better understanding of the proposed method, the calculated PSNR data for low data rate is shown in Table II and Table III for 10000 and 20000 bits respectively. If observed the tabulated values for various existing techniques and the proposed scheme, values of the proposed scheme give a much better average even for smaller embedding rate. The proposed algorithm performs even better for higher embedding rates. The values tabulated in the below Table II and Table III shows that the comparative schemes other than the proposed scheme are dependent on some characteristics of the image points. PSNR values keep changing for each image. But in the proposed scheme, since the algorithm is independent of image characteristics the PSNR value remains constant for all the image for an embedding rate.

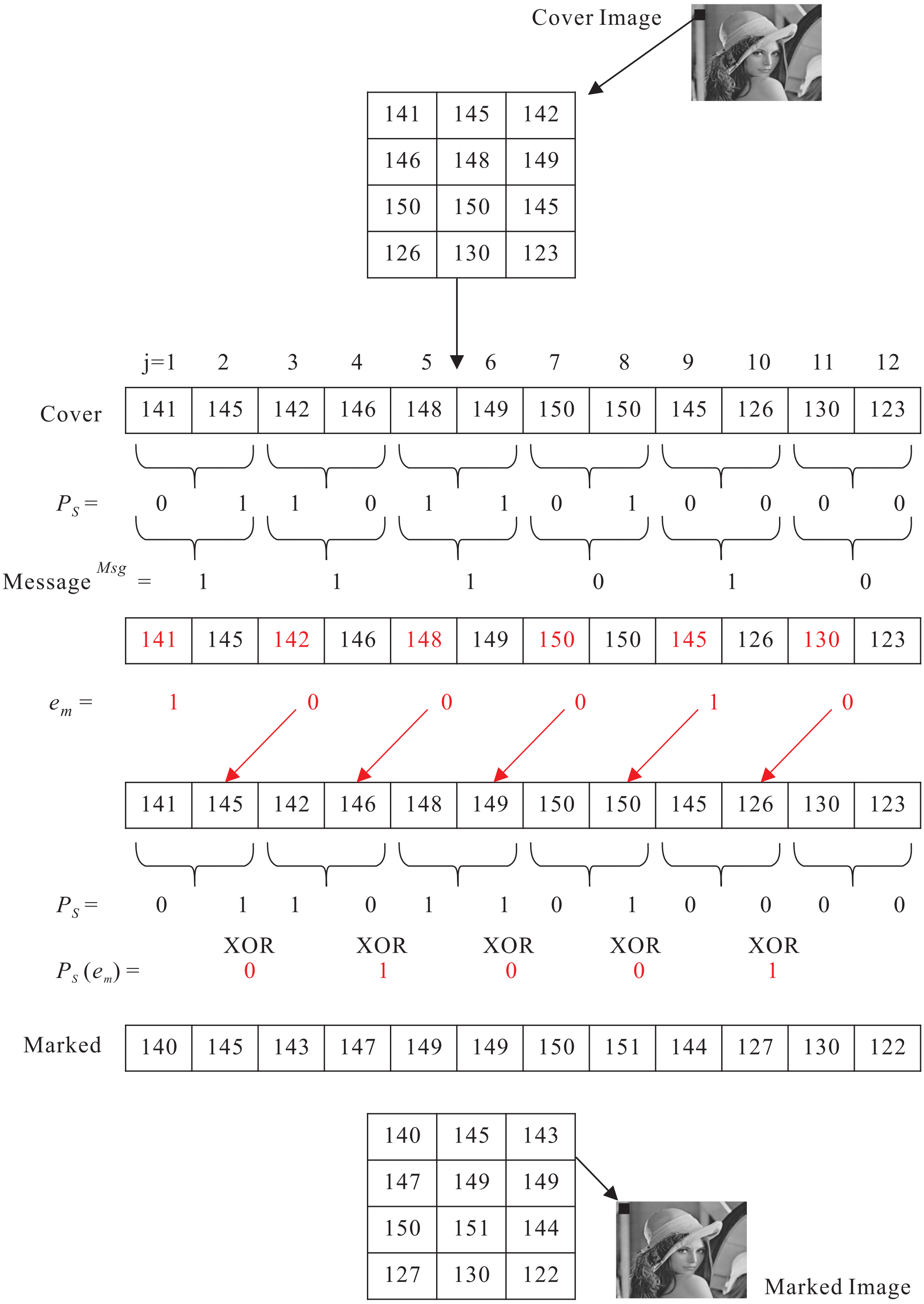
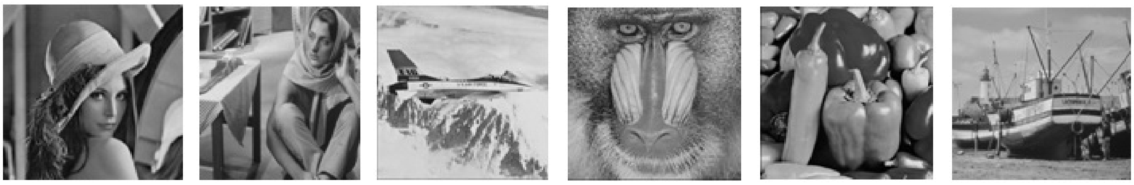


FIGURE 2. Explanation of the embedding strategy with numerical example

Underflow/Overflow:

The major drawback in all RDH techniques is identifying the locations, which may create underflow/ overflow issues, and creating a location map to bypass those points while performing embedding. In the proposed technique, such problem does not occur because, in this plus-minus technique any even point for e.g., 0 (zero) will undergo only a



(a) (b) (c) (d) (e) (f)

FIGURE 3. Standard test images: a) Lena b) Barbara c) Baboon d) Airplane e) Peppers f) Boat

TABLE 2. Comparison in terms of PSNR(dB) for a capacity of 10000 bits

Test Image	Sachnev[44]	Dragoi and coltuc[45]	Li[46]	Bo Ou[47]	Proposed method
Lena	58.216	58.939	58.167	59.748	59.86
Barbara	58.157	58.98	58.615	59.476	59.89
Airplane	60.559	62.276	61.268	63.755	59.89
Baboon	54.187	54.219	54.018	55.216	59.84
Peppers	56.27	56.35	56.33	56.92	59.87
Boat	56.169	56.247	55.508	57.545	59.84
Average	**57.259**	**57.835**	**57.317**	**58.776**	**59.86**

TABLE 3. Comparison in terms of PSNR(dB) for a capacity of 20000 bits

Test Image	Sachnev[44]	Dragoi and coltuc[45]	Li[46]	Bo Ou[47]	Proposed method
Lena	55.056	55.695	54.826	56.288	57.44
Barbara	55.058	55.689	55.289	56.265	57.43
Airplane	57.327	58.667	56.837	60.198	57.46
Baboon	49.419	49.558	48.286	50.118	57.47
Peppers	53.256	53.476	53.328	53.869	57.50
Boat	52.676	52.719	52.438	53.337	57.41
Average	**53.798**	**54.301**	**53.501**	**55.012**	**57.45**

plus and an odd point for e.g.: 255 will undergo only a minus. So there is no possibility for underflow/overflow in this algorithm. Even when the embedding is performed multiple numbers of times, the possibility for underflow/overflow is ruled out for this scheme.

Capacity controlling factor:

Total payload bit length comprises of $|\mathbb{P}|+|\mathbb{Q}|_{compressed}$ i.e., number of elements in $|\mathbb{P}|$ and $|\mathbb{Q}|$ where, $\mathbb{P}$ is the actual payload and $\mathbb{Q}$ is altered LSB required for reversibility. To maximize the embedding capacity $|\mathbb{Q}| \ll |\mathbb{P}|$. For single layer embedding $|\mathbb{Q}| \leq |\mathbb{P}|/3$. Embedding can be performed multiple times in the embedding part of the image, provided that the status of the pixel pair is noted and stored in the other half of the image before performing the next layer of embedding.

Table IV, V, VI shows the comparison metrics for a payload of 0.5 bpp, 1.0 bpp and 1.5 bpp for the proposed method. Comparison is done with few other high capacity embedding method like Li et al.,[46] and Gui et al.,[48] Since the proposed algorithm is

Table 4. Comparison in terms of PSNR(dB) for a capacity of 0.5bpp

Test Image	Sachnev[44]	Li[46]	Gui[48]	Proposed method
Lena	42.72	42.35	42.42	49.37
Barbara	40.21	41.02	41.77	49.39
Airplane	46.26	45.99	46.04	49.35
Baboon	32.21	31.44	32.00	49.35
Peppers	38.67	35.25	35.88	49.38
Boat	37.98	37.80	37.82	49.4
Average	**39.68**	**38.98**	**39.32**	**49.38**

Table 5. Comparison in terms of PSNR(dB) for a capacity of 1.0 bpp

Test Image	Li[46]	Gui[48]	Proposed method
Lena	34.58	35.38	48.15
Barbara	32.33	33.48	48.17
Airplane	37.78	38.52	48.18
Baboon	23.83	24.33	48.13
Peppers	31.26	32.13	48.16
Boat	30.69	31.21	48.19
Average	**31.75**	**32.51**	**48.16**

Table 6. Comparison in terms of PSNR(dB) for a capacity of 1.5 bpp

Test Image	Li[46]	Gui[48]	Proposed method
Lena	29.56	30.21	43.36
Barbara	25.49	27.48	43.38
Airplane	32.09	32.89	43.39
Baboon	-	-	43.33
Peppers	25.63	26.13	43.35
Boat	25.13	25.79	43.37
Average	**27.58**	**28.5**	**43.36**

independent of image characteristics, PSNR data remains almost similar to all the images and the performance is not affected by overflow/underflow image points.

The proposed method is experimented on medical images displayed in figure 4. In medical images most of the pixels are poised to either side of the intensity range 0 to $n - 1$ where $n = 2^x$ and x is the number of bits used to represent each pixel of image. Since there is no possibility for underflow/overflow in this algorithm, this method could be a perfect choice for embedding EPR information in medical images.

5. **Conclusion.** The proposed method described in this paper is based on ‘plus-minus one’ LSB embedding strategy. Standard embedding strategies like PEE, histogram modification, difference expansion is not involved in this technique. Embedding can be performed multiple times on a pixel pair, provided we preserve the pixel pair status information. Embedding performance is independent of image characteristics. The major issue of overflow/underflow is taken care with no record of the location map. Compression plays

a major role in our technique, as the status information is compressed and stored in the cover image itself. In this way, the proposed method outperforms some of the existing RDH techniques.

Compliance with Ethical Standards:
Conflict of Interest:
Author A declares that he/she has no conflict of interest.
Author B declares that he/she has no conflict of interest. ...
Ethical approval:
This article does not contain any studies with human participants performed by any of the authors.

(Or) Ethical approval: This article does not contain any studies with animals performed by any of the authors.

(Or) Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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