Secure Data Communication Through Improved Multi-level Pixel Value Ordering Using Center-Folding Strategy

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1 Introduction

The secret information is hidden under text documents, cover pictures, or any other types of multimedia as a data carrier in the data concealing technique in order for the recipient to effectively decipher the message. Reversible and irreversible information concealment techniques are based on the reconstruction of the original picture. Reversible data concealing techniques, also known as lossless information hiding, should always be used in sectors that are particularly susceptible to picture distortion, such as the medical, military, and scientific ones. Although non-reversible data hiding techniques normally have high embedding capacities, there are several limitations in the application domains since the cover image was irreparably lost after stuffing the secret information. After the extraction procedure is successfully finished, the secret data and the cover picture may be rebuilt. This study fixes secrets into image pixels using the RDH technique as its foundation. Reversible approaches can recreate the true cover picture after data extraction, whereas irreversible methods are insufficient to do so. In order to integrate hidden messages into cover graphics, this research explores reversible data concealing techniques.

In 2003, Tian [17] wrote up a method for hiding information within a pair of pixels called difference expansion (DE). It outlines how the picture was produced in order to get high embedding data with little distortion. A lossless information concealing

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approach that allows distortion to be completely erased from the annotated picture was presented by Lee et al. [3] in 2005. Additionally, the secret data was extracted from the marked picture. Li et al. [4] presented pixel value ordering-based information concealing techniques in 2013 where minimum and maximum pixels are regulated by information embedding. This demonstrates a high-fidelity RDH system for pictures using a novel approach that incorporates the information via prediction error expansion (PEE). Peng et al. [15] improved the PVO that Li et al. had shown by computing additional pixel differences and using new histogram modifications. Jana [1] has described a high payload-based data concealing approach using sub-sample. The remainder of the study is organized as follows: Sect. 2 explores the literature review. Section 3 explores the suggested embedding and extraction procedure. In Sect. 4, the comparisons and observational findings are discussed. The conclusions of the suggested approach are examined in Sect. 5.

2 Literature Review

Several reversible data hiding methods have recently been published by researchers. The center-folding method was used by Lu et al. [5] to approach reversible data concealing. It employs two copies of the original picture to achieve high embedding. The hidden message is folded and after that embedded into dual marked-images in this approach. In 2018, a technique [2] was put out to reduce distortion and preserve the authenticity of forgery alteration in dual stego-images. Meikap et al. [9–11] spoke about PVO-based RDH methods that improved the high data bit capability. In 2021, the [5] was changed from having a single layer to having numerous levels in order to present an improved interpolation-based concealment strategy [7]. Center-folding-based reversible information hiding methods [12, 13] were introduced in the year 2021. In 2022, [14] employed dual-image to build a shift technique that enables secret data to be inserted in those pixels that were previously exclusively altered in PVO-based schemes. The difficulty is to enhance payload by thinking about embedding in more than two pixels using references and neighboring pixels inside an image block after folding the message and inserting it into image pixels. To address these issues, we developed an improved multi-level PVO (IMPVO) with various block size information concealing mechanism based on center-folding. The strength of security is increased by our recommended approach. The q data set is used to translate the secrets into decimal values during the first embedding. Second, during second embedding, the embed procedure depends on the quantity and size of picture blocks. Third, the data is split across two pictures. The size of the image block, the quantity of image blocks, the value of q, and two stego-images are necessary for message retrieval. The aforementioned criteria are required if an unauthorized individual wants to view the message. Unauthorized individuals may find it challenging.

3 Proposed Method

In this part, we suggested the process of improved multi-level PVO (IMPVO) secret embedding and extraction using the center-folding approach. By maintaining picture quality along with our recommended improved multi-level PVO method, we seek to maximize the embedding capacity. The following stages are used to organize the whole procedure.

3.1 Data Embedding Phase

Step 1: By averaging the neighboring pixels, we enlarge these pictures using the interpolation technique presented in Fig. 1. If the picture size is $(w \times w)$, the interpolated image will be $(w + (w - 1)) \times (w + (w - 1))$, where $(w - 1)$ is the interpolated row/column. For making rows and columns even, one is added to each, and the previous row's and column's value is copied.

Step 2: The cover picture is $IC = \{pix_{1,1}, \ldots, pix_{w,h}\}$, where w as well as h stand for width and height of image, respectively. Every q bit is taken as a set by the secret information, which is then modified to a decimal using the hidden symbol d_s. The symbol range is then adjusted from $Q = \{0, 1, \ldots, 2^q - 1\}$ to $R' = \{-2^{q-1}, -2^{q-1} + 1, \ldots, -1, 0, 1, \ldots, 2^{q-1} - 2, 2^{q-1} - 1\}$ using the concealed symbol d_s. The following formula may be used to determine the folded hidden symbol d_s':

$$d_s' = d_s - 2^{q-1} \tag{1}$$

where 2^{q-1} denotes in-between values. The process of inserting concealed data can be done by

$$\begin{cases} d_{s1}' = \left\lfloor \frac{d_s'}{2} \right\rfloor, \\ d_{s2}' = \left\lceil \frac{d_s'}{2} \right\rceil. \end{cases} \tag{2}$$

(a) Original image

(b) Interpolated image

$pix_5 = (pix_1 + pix_2) / 2$
$pix_6 = (pix_1 + pix_3) / 2$
$pix_7 = (pix_1 + pix_2 + pix_3 + pix_4) / 4$
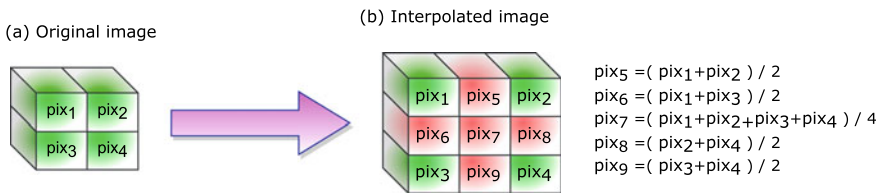$pix_8 = (pix_2 + pix_4) / 2$
$pix_9 = (pix_3 + pix_4) / 2$

Fig. 1 Creation of interpolated image. Pink color represents interpolate row and column

Here, d'_{s1} as well as d'_{s2} are obtained from d'_s. The following equations create dual marked pixels $pix^1_{i,j}$ and $pix^2_{i,j}$ by inserting these values into the pixel $pix_{i,j}$.

$$
\begin{cases}
pix^1_{i,j} = pix_{i,j} + d'_{s1}, \\
pix^2_{i,j} = pix_{i,j} - d'_{s2}.
\end{cases}
\tag{3}
$$

The hidden data is concealed in pixels between 2^{q-1} and $256 - 2^{q-1}$.

Step 3: The dual interpolated stego pictures are divided into separate, overlapping K blocks in this stage. All pixels are arranged in ascending order inside each block. The threshold T value between 0 and 255 is set to have the least amount of distortion throughout the data embedding procedure. If pixels are close together, median and neighbor pixel differences are modest. When $CL \leq T$, data may be hidden, and the picture block is viewed as smooth. The picture block will be handled as a rough block if complexity level $CL > T$ since it cannot conceal the contents. The median value is calculated from a block's sorted pixels. The reference pixel M used to represent this median value. The n pixels that surround the current block in the left, bottom, right, and top positions are referred to as its neighbor pixels O_P. The complexity level CL is calculated as the sum of the absolute differences between each neighboring pixel and the reference pixel. This is produced using the formula (4).

$$
CL = \sum |O_P - M|
\tag{4}
$$

It has two median values for even-numbered pixels. For this, the median value with the high positioned is chosen as M. It comprises one median value that is chosen for M for pixels with an odd number. Equations (6) and (5) are used to produce the reference pixel M and its location ml from an image block ($wbl \times hbl$) comprising n pixels.

$$
ml = \begin{cases}
\frac{(wbl \times hbl)+1}{2} & \text{if } n = \text{ODD}, \\
\frac{(wbl \times hbl)}{2} + 1 & \text{if } n = \text{EVEN}.
\end{cases}
\tag{5}
$$

$$
M = \begin{cases}
b_{\sigma_{\frac{(wbl \times hbl)+1}{2}}} & \text{if } n = \text{ODD}, \\
b_{\sigma_{\frac{(wbl \times hbl)}{2}+1}} & \text{if } n = \text{EVEN}.
\end{cases}
\tag{6}
$$

The arrangement of the pixels in a block is hampered since the secrets are integrated into more than one minimum and/or maximum pixel in this instance. We introduce the η value to keep the order. Maximum pixels are increased by *eta*, while

minimum pixels are decreased. The value of η changes after each repetition. Lemma 1 and Lemma 2 affect how much η is worth.

Lemma 1 *If the number of pixels of a block is $bl_{w \times h}$=ODD and increasing wise sorted pixels are $(pix_1, pix_2, \ldots, b_{(w \times h)})$ where the range of i is $1 \leq i \leq (w \times h)$. Then, the altered pixels are $(pix_1 - \eta_{fix(\frac{w \times h}{2})-1}, pix_2 - \eta_{fix(\frac{w \times h}{2})-1-1}, \ldots, pix_{(w \times h)-1}$ $+ \eta_{fix(\frac{w \times h}{2})-1-1}, pix_{(w \times h)} + \eta_{fix(\frac{w \times h}{2})-1})$, where, the $\eta_{fix(\frac{w \times h}{2})-1} = fix(\frac{w \times h}{2}) - 1$. The maximal and minimal values of η are $(fix(\frac{w \times h}{2}) - 1)$ and 0, respectively.*

Lemma 2 *If the number of pixels of a block is $bl_{w \times h}$ = even_number and ascending order sorted pixels are $(pix_1, pix_2, \ldots, pix_{(w \times h)})$ where the range of i is $1 \leq i \leq (w \times h)$. Then, the altered pixels are $(pix_1 - \eta_{fix(\frac{w \times h}{2})-1}, pix_2 - \eta_{fix(\frac{w \times h}{2})-1-1}, \ldots,$ $pix_{(w \times h)-1} + \eta_{fix(\frac{w \times h}{2})-2-1}, pix_{(w \times h)} + \eta_{fix(\frac{w \times h}{2})-2})$, where the $\eta_{fix(\frac{w \times h}{2})-1} = fix(\frac{w \times h}{2})$ $- 1$. The maximal and minimal η are $(fix(\frac{w \times h}{2}) - 1)$ and 0 respectively for minimal numbered pixels and the maximal and minimal η are $(fix(\frac{w \times h}{2}) - 2)$ and 0 respectively for maximal numbered pixels.*

The pixels in an image block contain the relevant data. The following is the embedding approach:

Embedding in Minimum-Modification Assume that a sub-block bl has n pixels in it. All pixels in the sub-block are sorted in a rising-up order to produce $(pix_{\sigma(1)}, \ldots, pix_{\sigma(n)})$. We compute

$$d_{\min_r} = pix_E - pix_F, \quad \text{where} \quad \begin{cases} E = \max(\sigma((1) + r), \sigma(ml)), \\ F = \min(\sigma((1) + r), \sigma(ml)), \\ r = (0, 1, \ldots, fix(n/2) - 1). \end{cases} \quad (7)$$

Rounding the output data toward 0 is done using the fix(). The smallest pixels are now converted to $pixel'$. Each action involves a modification to η. The changed minimum pixels are obtained by

$$pixel' = \begin{cases} (pix_{\sigma((1)+r)} - \eta) - D, & \text{if } d_{\min_r} = 0, \\ (pix_{\sigma((1)+r)} - \eta) - 1, & \text{if } d_{\min_r} > 0, \\ (pix_{\sigma((1)+r)} - \eta) - D, & \text{if } d_{\min_r} = -1, \\ (pix_{\sigma((1)+r)} - \eta) - 1, & \text{if } d_{\min_r} < -1. \end{cases} \quad (8)$$

where pixels with the value $D \in \{0, 1\}$ are added.

Embedding in Maximum-Modification The following is a discussion of the data that is inserted into pixels for maximum-modification: Determine,
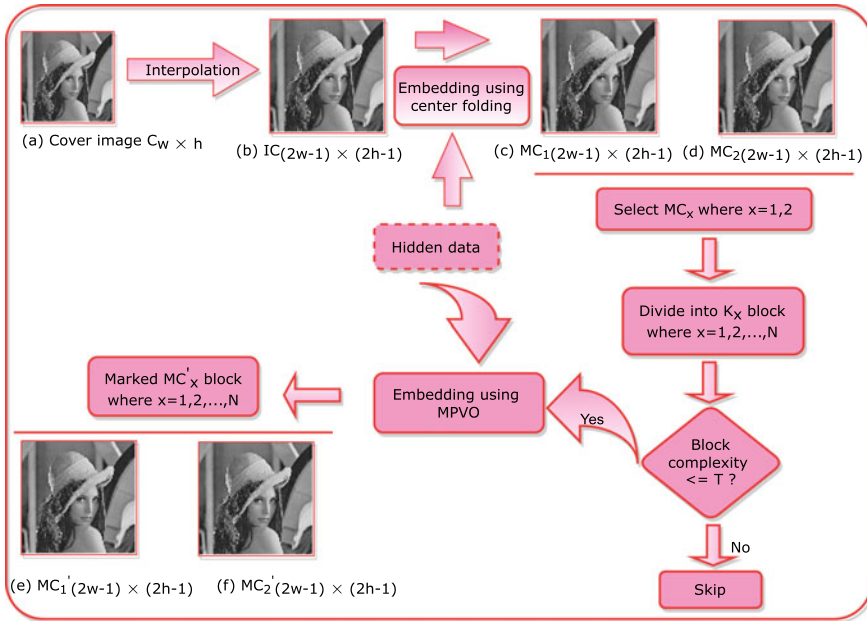
Fig. 2 Overall data embedding process in proposed IMPVO scheme

$$d_{\max_r} = pix_G - pix_H, \quad \text{where} \quad \begin{cases} G = \max(\sigma((n) - r), \sigma(ml)), \\ H = \min(\sigma((n) - r), \sigma(ml)), \\ r = (0, 1, \ldots, \text{fix}(n/2) - 1) \text{ if } n = \text{ODD}, \\ \quad = (0, 1, \ldots, \text{fix}(n/2) - 2) \text{ if } n = \text{EVEN}. \end{cases} \quad (9)$$

The maximum pixels are now converted to $pixel'$. Each action involves a modification to η. The changed maximum pixels are obtained by

$$pixel' = \begin{cases} (pix_{\sigma((n)-r)} + \eta) + D, & \text{if } d_{\max_r} = 0, \\ (pix_{\sigma((n)-r)} + \eta) + 1, & \text{if } d_{\max_r} > 0, \\ (pix_{\sigma((n)-r)} + \eta) + D, & \text{if } d_{\max_r} = -1, \\ (pix_{\sigma((n)-r)} + \eta) + 1, & \text{if } d_{\max_r} < -1. \end{cases} \quad (10)$$

where pixels with the value $D \in \{0, 1\}$ are added. Figure 2 shows the whole embedding procedure.

3.2 Extraction Phase

Step 1: The cover image and secret data are retrieved in the reverse order at the receiver end using the same process. The stego pictures are transformed into the overlapping K blocks. The arrangement of the pixels in each block remains the same after sorting. Equations (6) and (4) reused to create the M and CL, respectively. The same threshold value is used in the data extraction. The data in this case are taken from many minimum and/or maximum values. Pixel order may thus vary. The value of η maintains the order of the pixels. Lemma 3 and Lemma 4 both have an impact on the value of η.

Lemma 3 *If the number of pixels of a block is $bl_{w \times h}$=ODD and increasing wise sorted pixels are $(pix_1, pix_2, \ldots, pix_{(w \times h)})$ where the range of i is $1 \leq i \leq (w \times h)$. Then, the altered pixels are $(pix_1 + \eta_{fix(\frac{w \times h}{2})-1}, pix_2 + \eta_{fix(\frac{w \times h}{2})-1-1}, \ldots, pix_{(w \times h)-1} - \eta_{fix(\frac{w \times h}{2})-1-1}, pix_{(w \times h)} - \eta_{fix(\frac{w \times h}{2})-1})$, where the $\eta_{fix(\frac{w \times h}{2})-1} = fix(\frac{w \times h}{2}) - 1$. The maximal and minimal values of η are $(fix(\frac{w \times h}{2}) - 1)$ and 0, respectively.*

Lemma 4 *If the number of pixels of a block is $bl_{w \times h}$ = EVEN and increasing wise sorted pixels are $(pix_1, pix_2, \ldots, pix_{(w \times h)})$ where the range of i is $1 \leq i \leq (w \times h)$. Then, the altered pixels are $(pix_1 + \eta_{fix(\frac{w \times h}{2})-1}, pix_2 + \eta_{fix(\frac{w \times h}{2})-1-1}, \ldots, pix_{(w \times h)-1} - \eta_{fix(\frac{w \times h}{2})-2-1}, pix_{(w \times h)} - \eta_{fix(\frac{w \times h}{2})-2})$, where the $\eta_{fix(\frac{w \times h}{2})-1} = fix(\frac{w \times h}{2}) - 1$. The maximal and minimal β are $(fix(\frac{w \times h}{2}) - 1)$ and 0, respectively, for minimal numbered pixels and the maximal and minimal η are $(fix(\frac{w \times h}{2}) - 2)$ and 0, respectively, for maximal numbered pixels.*

Extraction in Minimum-Modification The extraction of message as well as reconstruction of the picture are done with the minimum-pixel alteration. Assume that the value has changed to $(cpixel_1, cpixel_2, \ldots, cpixel_n)$. The mapping σ is constant. We derive the equation $d'_{\min_r} = cpixel_E - cpixel_F$, where (E, F, r) are described in Eq. (7).

- When $d'_{\min_r} > -1$, then $cpixel_E \geq cpixel_F$. Here, $E = \sigma(ml)$, $F = \sigma((1) + r)$ and $\sigma((1) + r) < \sigma(ml)$:

  - When $d'_{\min_r} \in \{0, 1\}$, the data is $D = d'_{\min_r}$. The smallest pixel is $cpixel_{\sigma((1)+r)} = (cpixel_F + \eta) + D$;
  - When $d'_{\min_r} > 1$, their is no data. The smallest pixel is $cpixel_{\sigma((1)+r)} = (cpixel_F + \eta) + 1$.

- When $d'_{\min_r} \leq -1$, then $cpixel_E < cpixel_F$. Here, $E = \sigma((1) + r)$, $F = \sigma(ml)$ and $\sigma((1) + r) > \sigma(ml)$:

  - When $d'_{\min_r} \in \{-1, -2\}$, the data is $D = -d'_{\min_r} - 1$. The smallest pixel is $cpixel_{\sigma((1)+r)} = (cpixel_E + \eta) + D$;

- When $d'_{\min_r} < -2$, their is no data. The smallest pixel is $cpixel_{\sigma((1)+r)} = (cpixel_E + \eta) + 1$.

Extraction in Maximum-Modification We find that $d'_{\max_r} = cpixel_G - cpixel_H$. Where (G, H, r) is a list in the Eq. (9).

- When $d'_{\max_r} > -1$, then $cpixel_G \geq cpixel_H$. Here, $G = \sigma((n) - r)$, $H = \sigma(ml)$ and $\sigma(ml) < \sigma((n) - r)$:

  - When $d'_{\max_r} \in \{0, 1\}$, the data is $D = d'_{\max_r}$. The largest pixel is $cpixel_{\sigma((n)-r)} = (cpixel_G - \eta) - D$;
  - When $d'_{\max_r} > 1$, their is no data. The largest pixel is $cpixel_{\sigma((n)-r)} = (cpixel_G - \eta) - 1$.

- When $d'_{\max_r} \leq -1$, then $cpixel_G < cpixel_H$. Here, $G = \sigma(ml)$, $H = \sigma((n) - r)$ and $\sigma(ml) > \sigma((n) - r)$:

  - When $d'_{\max_r} \in \{-1, -2\}$, the data $D = -d'_{\max_r} - 1$. The largest pixel is $cpixel_{\sigma((n)-r)} = (cpixel_H - \eta) - D$;
  - When $d'_{\max_r} < -2$, their is no data. The largest pixel is $cpixel_{\sigma((n)-r)} = (cpixel_H - \eta) - 1$.

Now, recovered the secret message as well as images of $MC1_{(2w-1)\times(2h-1)}$ and $MC2_{(2w-1)\times(2h-1)}$.

Step 2: In this stage, using the following formulas, we extract the message from the stego pixels $pix^1_{i,j}$ and $pix^2_{i,j}$ of the interpolated marked pictures $MC1_{(2w-1)\times(2h-1)}$ and $MC2_{(2w-1)\times(2h-1)}$, respectively.

$$d'_s = pix^1_{i,j} - pixel^2_{i,j} \tag{11}$$

$$d_s = d'_s + 2^{q-1} \tag{12}$$

where q represents how many concealed bits make up a group. The following is the reconstruction of the actual pixel, $pix_{i,j}$.

$$pix_{i,j} = \left\lceil \frac{pix^1_{i,j} + pix^2_{i,j}}{2} \right\rceil \tag{13}$$

Now construct the interpolated cover image $IC_{(2w-1)\times(2h-1)}$.

Step 3: Now, rebuild the cover image $C_{w \times h}$ from interpolated cover image $IC_{(2w-1) \times (2h-1)}$ by removing any interpolated columns and rows.

4 Experimental Results and Comparisons

This paragraph compares the proposed scheme's execution to those of the previous dual-image-based secrets concealment systems developed by Authors [2, 5, 6, 16]. Peppers, Lena, Baboon, Fishing boat, Airplane F 16, and Barbara were selected from [18] database, while CXR1000_IM-0003-1001 and CXR1025_IM-0020-1001 were obtained from the [8] database as test inputs for study. All gray-scale image size is (256 × 256). Only USC-SIPI photos are shown in Fig. 3.

The embedding of secrets depends on q and block size. The picture quality is found to be higher in small values of q with large blocks but not much larger block

Fig. 3 For our experiments, the six standard photos are used as input

Table 1 The secrets embedding (EC) in bits with separate p of two separate database pictures with average PSNR (dB)

Database	Cover image (C)	q	$PSNR_1$ (Avg.)	$PSNR_2$ (Avg.)	Average PSNR	EC_1 (IMI_1')	EC_2 (IMI_2')	$EC = EC_1 + EC_2$
USC-SIPI	Lena	2	51.87	53.27	52.57	320,829	280,512,983	601,341
		3	50.21	49.30	49.75	398,613	396,112	794,725
		4	46.39	43.55	44.97	482,731	529,805	1,012,536
	Airplane F16	2	52.38	50.72	51.55	289,437	305,515	594,952
		3	49.13	47.06	48.09	387,659	409,034	796,693
		4	45.89	44.63	45.26	465,120	501,269	966,389
	Fishing boat	2	51.89	51.56	51.77	276,813	309,320	586,133
		3	46.65	46.32	46.48	399,295	396,892	796,187
		4	44.52	43.89	44.20	481,715	505,216	986,931
National library of medicine	CXR1025_IM-0020-1001	2	51.12	52.89	52.00	308,224	290,617	598,841
		3	49.66	48.06	48.86	425,320	398,612	833,932
		4	45.18	45.62	45.40	510,291	495,697	1,005,988
	CXR1000_IM-0003-1001	2	51.40	52.16	51.78	298,032	326,514	624,546
		3	48.37	46.62	47.49	402,910	411,853	814,763
		4	46.53	45.19	45.86	503,841	525,472	1,029,313

Table 2 Comparison among the other schemes and the proposed scheme with image quality in PSNR (dB) as well as embedding capacity (EC) in bits

Schemes	Measure	Lena	Baboon	Peppers	Barbara	Fishing boat
Qin et al. [16]	$PSNR_1$	52.11	52.04	51.25	52.12	52.11
	$PSNR_2$	41.58	41.56	41.52	41.58	41.57
	Avg. PSNR	46.85	46.80	46.39	46.85	46.84
	EC	557,052	557,096	557,245	557,339	557,194
Lu et al. [6]	$PSNR_1$	49.20	49.21	49.19	49.22	49.20
	$PSNR_2$	49.21	49.20	49.21	49.20	49.21
	Avg. PSNR	49.21	49.21	49.20	49.21	49.21
	EC	524,288	524,204	524,192	524,288	524,284
Lu et al. ($k = 2$) [5]	$PSNR_1$	49.89	49.89	49.89	49.89	49.89
	$PSNR_2$	52.90	52.87	52.92	52.90	52.90
	Avg. PSNR	51.40	51.38	51.41	51.40	51.40
	EC	524,288	524,172	523,780	524,288	524,286
Jung [2]	$PSNR_1$	48.18	48.17	48.18	–	48.18
	$PSNR_2$	48.18	48.16	48.18	–	48.18
	Avg. PSNR	48.18	48.16	48.18	–	48.18
	EC	519,180	519,180	519,180	–	519,180
Proposed method ($q = 2$)	$PSNR_1$	51.87	52.30	51.89	52.66	51.89
	$PSNR_2$	53.27	51.38	52.21	51.18	51.66
	Avg. PSNR	52.57	51.84	52.05	51.92	51.77
	EC	601,341	591,322	594,751	604,643	586,133

size than in large values of q, but the message embedding rate is low. For instance, in the Lena image, 601,341 bits are added with an average peak signal-to-noise ratio (PSNR) of 52.57 dB when $q = 2$. In the picture Lena presented in Table 1, when $q = 3,794,725$ bits are inserted with an average PSNR of 49.75, whereas when $q = 41,012,536$ bits are placed with an average PSNR of 44.97.

Table 2 shows the PSNR (dB) comparisons between the suggested and previous techniques. The new approach improves the secrets capacity (EC) calculated using other PVO-based approaches. While the value of q is 2 as stated in Table 2, the hidden message capacity is 442,89, 77,053, 77,053, and 82,161 bits larger than that of Qin et al.'s [16], Lu et al.'s [6], Lu et al.'s [5] and Jung [2], respectively, for the picture Lena. The capacity of information concealment in input images is increased by the proposed approach. It has been determined that our approach outperforms existing PVO techniques in terms of payload while maintaining the same level of picture quality. Additionally, it is obvious that the picture quality is superior to other current schemes, as illustrated in Fig. 4.
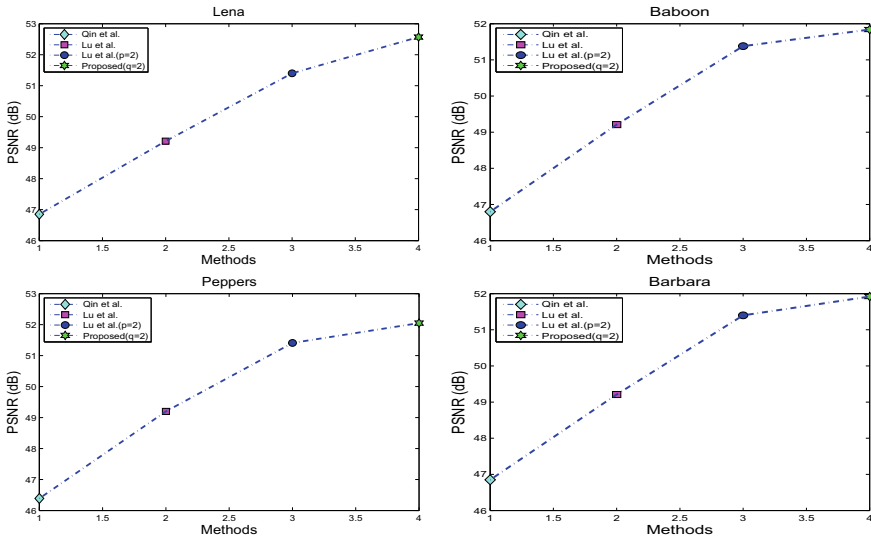
Fig. 4 Image quality comparisons between approaches in terms of PSNR (dB) of [5, 6, 16] and proposed technique with $2 = 2$

5   Conclusion

With varied sizes for the q (set of data) and picture block, this work suggested an improved multi-level PVO (IMPVO) utilizing the center-folding technique. Huge messages are put into and taken from image pixels using the algorithms for inserting and retrieving, respectively. The proposed approach enables safe message transmission by inserting secrets between two pictures. When q is 2, our technique produces a PSNR value over 51 dB and an embedding capacity over 585,000 bits. The suggested approach yields successful outcomes. It is found that the recommended system looks to perform better than other PVO efforts.

References

1. Jana B (2017) Reversible data hiding scheme using sub-sampled image exploiting Lagrange's interpolating polynomial. Multimedia Tools Appl 1–17
2. Jung KH (2018) Authenticable reversible data hiding scheme with less distortion in dual stego-images. Multimedia Tools Appl 77:6225–6241
3. Lee SK, Suh YH, Ho YS (2004, November) Lossless data hiding based on histogram modification of difference images. Pacific-Rim conference on multimedia. Springer, Berlin, Heidelberg, pp 340–347
4. Li X, Li J, Li B, Yang B (2013) High-fidelity reversible data hiding scheme based on pixel-value-ordering and prediction-error expansion. Sig Process 93(1):198–205

5. Lu TC, Wu JH, Huang CC (2015) Dual-image-based reversible data hiding method using center folding strategy. Sig Process 115:195–213
6. Lu TC, Tseng CY, Wu JH (2015) Dual imaging-based reversible hiding technique using LSB matching. Sig Process 108:77–89
7. Lu TC, Huang SR, Huang SW (2021) Reversible hiding method for interpolation images featuring a multilayer center folding strategy. Soft Comput 25:161–180
8. The National Library of Medicine presents MedPix Superscript Registered MedPix®. https://openi.nlm.nih.gov/gridquery.php?q=&it=x
9. Meikap S, Jana B (2017) Extended directional IPVO for reversible data hiding scheme. Communication, devices, and computing. Springer, Singapore, pp 47–58
10. Meikap S, Jana B (2018) Directional PVO for reversible data hiding scheme with image interpolation. Multimedia Tools Appl 77(23):31281–31311
11. Meikap S, Jana B (2019) Directional pixel value ordering based secret sharing using sub-sampled image exploiting Lagrange polynomial. SN Appl Sci 1(6):645
12. Meikap S, Jana B (2021) Improved center-folding based directional pixel value ordering for reversible data hiding scheme. Multimedia Tools Appl 80(4):5617–5652
13. Sudipta M, Biswapati J, Prasenjit B, Kumar SP (2021) High payload RDH through directional PVO exploiting center-folding strategy. In: Proceedings of international conference on frontiers in computing and systems. Springer, Singapore, pp 659–670
14. Niu Y, Shen S (2022) A novel pixel value ordering reversible data hiding based on dual-image. Multimedia Tools Appl 81(10):13751–13771
15. Peng F, Li X, Yang B (2014) Improved PVO-based reversible data hiding. Digital Sig Process 25:255–265
16. Qin C, Chang CC, Hsu TJ (2015) Reversible data hiding scheme based on exploiting modification direction with two steganographic images. Multimedia Tools Appl 74(15):5861–5872
17. Tian J (2003) Reversible data embedding using a difference expansion. IEEE Trans Circuits Syst Video Technol 13(8):890–896
18. University of Southern California. The USC-SIPI Image Database. http://sipi.usc.edu/database/database.php?volume=misc