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A Higher Efficient Reversible Data Hiding Scheme Based on Pixel Value Ordering

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Abstract. *In recent years, the reversible data hiding (RDH) scheme based on pixel-value-ordering and prediction-error expansion proposed by Li et al has become a hot research topic for its high-fidelity. In this scheme, the difference between the second maximum and second minimum value is used to measure the complexity of each pixel block, and the flat block which complexity is less than a predefined threshold T is prior used to embed secret data. The pixel block selection strategy is easy, but it is not always effective. The embedding efficiency is not high when a small amount of secret information is embedded. In this paper, a higher efficient reversible data hiding scheme based on pixel value ordering is proposed. In this work, instead of the difference between the second maximum and second minimum value of a block, the standard deviation is used to measure the complexity. The proposed scheme could adaptively adjust the threshold according to the embedded capacity for higher embedding efficiency. The experimental results show that the proposed scheme has higher embedding efficiency and better image quality compared with Li et al.s.*
Keywords: Reversible data hiding, Pixel value ordering, Pixel block, Embedding efficiency, Standard deviation

1. **Introduction.** Data hiding [1] is a kind of technology that imbeds secret information into host media such as audio, image and video, and the embedded secret information will not be perceived. Image data hiding conceals the secret information by modifying the pixel value in a certain way. It is obvious that the data hiding process inevitably causes distortion. Data hiding can be divided into reversible data hiding (RDH) [2–4] and irreversible data hiding [5, 6] according to whether the cover image can be recovered completely after the secret information extracted. Reversible data hiding is suitable for the scene with high requirements for the original cover image [7,8], such as crime detection, military, intelligence, medical, or other sensitive data fields. For example, the diagnostic image contains patients information transferred to doctors by the telemedicine system is required to be fully restored after secret information extracted. Any distortion could cause a doctor to make a mistake, it is not hoped to happen. Therefore, reversible data hiding has become a hot research issue.

In the past few years, many reversible data hiding methods have been proposed. Early reversible data hiding algorithms are mainly based on lossless compression [9–11]. The embedding space of these algorithms is produced by lossless compressing the cover image. The embedding capacity is determined by compression ratio. However, these methods usually provide a low embedding capacity (EC) and low image quality.

Difference expansion (DE) scheme is firstly proposed by Tian [12]. In DE, the secret data is embedded by expanding the difference between adjacent pixels. DE achieves a good performance because the correlation between adjacent pixels are exploited. Compared with the RDH based on lossless compression, the DE technique can provide a much higher embedding capacity (EC) and better image quality. DE is developed for higher capacity by Alattar [13], in which the difference expansion of vectors of adjacent pixels can hide several bits. Obviously, if n is large enough, the embedding rate can reach 1bpp. Weng et al. [14] proposed a reversible watermarking based on invariability and adjustment on pixel pairs. In his scheme, one pixel adds a value while another minus the value, the sum of these two pixels will remain unchanged, and an integer transform is designed to hide secret data. Compared with the scheme proposed by Coltuc [15], Wengs method has better performance in embedding capacity and image quality. Prediction error expansion (PEE) proposed by Thodi and Rodriguez [16, 17] is an important extension of DE. PEE uses each pixel's prediction error instead of the pixels difference to embed data, and it has good performance [18–20].

Histogram Shifting (HS) is another important scheme for RDH, which is first proposed by Ni et al. [21]. In this scheme, the peak points of image histogram are modified to embed data. The embedding capacity of HS determined by the number of pixels in the peak point. People usually construct a sharper histogram for high embedding capacity [22, 23].

In 2013, Li et al. proposed a reversible data hiding (RDH) scheme [24] which has better performance based on pixel-value-ordering and prediction-error expansion. Generally, Li's scheme is called PVO method for convenience. In PVO method, the pixels in a block are first sorted and then the maximum/minimum pixel value is predicted by the second maximum/minimum pixel value. Finally, the pixel with prediction error equal to 1 is embedded with one secret bit. The accuracy of the prediction error of the PVO method is very high and the embedding performance is improved. In addition, Li et al. use the difference between the second maximum and second minimum pixel value to measure the complexity of each pixel block. In the process of data hiding, the flat block which complexity is less than a predefined threshold T is prior used to embed secret data. This further improves the performance of the algorithm. Then, many data hiding algorithms based PVO have been published [8, 25–29].

The block with prediction error equal to 0 is not utilized in PVO method. For fully exploiting embedding capacity, PVO-k scheme is proposed by Ou et al. [25] using a similar mechanism as that of [24], where k is the number of the maximum/minimum pixels in the pixel block. PVO-1 is just the conventional PVO-based while the maximum/minimum pixels are considered as a unit for embedding secret information in PVO-2. In order to achieve greater embedding capacity, Peng et al. [26] proposed an improved PVO (IPVO) method. In IPVO, the difference is defined considering the pixel locations of the maximum/minimum and second maximum/minimum value [26]. The potential embedding capacity of PVO is fully exploited in this way. The pixel-based pixel value ordering(PPVO) which is proposed by Qu et al. [27] uses the concept of target pixel context to predict the single target pixel and obtains greater embedding capacity.

It's an important aspect of improving the PEE method by enhancing the accuracy of the prediction error [30]. The difference between the second maximum and second minimum value is used to measure the complexity of each pixel block [24], and the complex pixel block is removed. Most of the methods based on PVO inherit this pixel block selection strategy. This strategy is not accurate enough to reflect the complexity of pixel block, and it has a shortage. To solve this problem, a higher efficiency reversible data hiding scheme based PVO (HEPVO) is proposed. The standard deviation is used as threshold T to measure the pixel block complexity in the proposed method. The complex block is abandoned, and the embedding efficiency is improved. The experiment is carried out from two aspects of embedding efficiency and image quality, which shows that the proposed method has better performance.

The rest of paper is organized as follows: in Section 2, PVO scheme is reviewed briefly. In Section 3, pixel block selection strategy is analysis. Proposed scheme (HEPVO) is described in Section 4. Experimental results and security analysis are provided in Section 5. Finally, we conclude our work in Section 6.

2. **PVO scheme.** First, the cover image is divided into non-overlapped blocks which contains n pixels. The pixel value (x_1, x_2, ..., x_n) is sorted in ascending order to obtain ($x_{\sigma(1)}$, $x_{\sigma(2)}$, ..., $x_{\sigma(n)}$). If one of the conditions (1) is met, it would cause overflow/underflow after being expanded or shifted in PEE for a block X_i. Then set the overflow/underflow location map $LM(i) = 1$. Otherwise, set the $LM(i) = 0$.

$$\begin{cases} x_{\sigma(n)} - x_{\sigma(n-1)} \geq 1 \quad and \quad x_{\sigma(n)} = 255 \\ x_{\sigma(1)} - x_{\sigma(2)} \leq -1 \quad and \quad x_{\sigma(1)} = 0 \end{cases} \tag{1}$$

The prediction error PE_{max} and PE_{min} is produced according to

$$\begin{cases} PE_{max} = x_{\sigma(n)} - x_{\sigma(n-1)} \\ PE_{min} = x_{\sigma(1)} - x_{\sigma(2)} \end{cases} \tag{2}$$

Secret data can be embedded according to

$$\widetilde{PE}_{max} = \begin{cases} PE_{max} & if \quad PE_{max} = 0 \\ PE_{max} + b & if \quad PE_{max} = 1 \\ PE_{max} + 1 & if \quad PE_{max} > 1 \end{cases} \tag{3}$$

$$\widetilde{PE}_{min} = \begin{cases} PE_{min} & if \quad PE_{min} = 0 \\ PE_{min} - b & if \quad PE_{min} = -1 \\ PE_{min} - 1 & if \quad PE_{min} < -1 \end{cases} \tag{4}$$

where b∈{0,1} is a secret information bit. Finally, the maximum/minimum pixel is modified according to

$$\begin{cases} \widetilde{x}_{\sigma(n)} = x_{\sigma(n-1)} + \widetilde{PE}_{max} \\ \widetilde{x}_{\sigma(1)} = x_{\sigma(2)} - \widetilde{PE}_{min} \end{cases} \tag{5}$$

The complexity of a block X is measured according to Eq. (6), and the flat block is prior used to embed data.

$$T = x_{\sigma(n-1)} - x_{\sigma(2)} \tag{6}$$

3. **PVO scheme.**

3.1. **The pixel block selection strategy of PVO.**

Flat blocks is more favorable for reversible data hiding [17]. The flat block which complexity is less than the threshold T is prior used to embed data in PVO method. The method is simple, but it is not always effective. Especially at low embedding rate, the PVO still has lower embedding efficiency. The embedding efficiency of the PVO method at different threshold is shown in Figure 1.

In the smooth region, the prediction error of the PEE method is more accurate. In this case, the embedding efficiency is improved, and the distortion caused by embedding the secret information is reduced. Normally, a lot of complex pixel blocks should be abandoned when the threshold T is relatively small. This approach makes the embedding efficiency higher. On the contrary, the embedding efficiency decreases rapidly while the threshold T

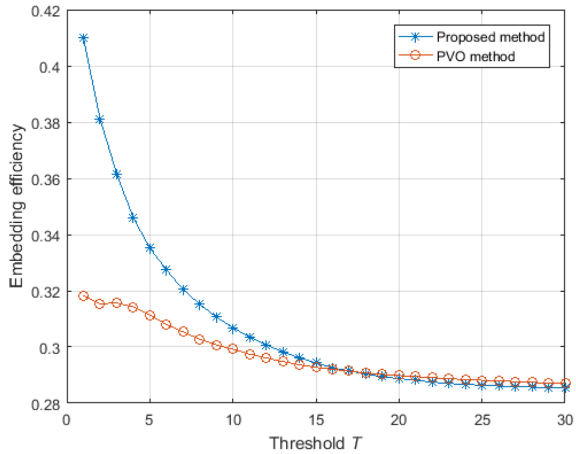

FIGURE 1. Threshold - embedding efficiency

increases. If the change of the threshold T has little influence on the embedding efficiency, the pixel block selection strategy needs to be improved.

The embedding efficiency curve of PVO method is shown in Figure 1. In the graph, the threshold T takes different values. It is easy to know that when the threshold is 1, the maximum embedding efficiency is 0.3182. When the threshold value is 30, the embedding efficiency is 0.2870. The embedding efficiency changes slowly when threshold increases.

3.2. **Improved pixel block selection strategy.** Through the analysis above, the pixel block selection strategy adopted by the PVO method has defects. Therefore, this paper tries to find a better performance strategy for pixel block selection.

The standard deviation reflects the discrete degree of pixel value in pixel block, which can more objectively reflect the complexity of pixel block. The standard deviation is shown in the formula (7), and the symbol μ denotes the mean value.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{7}$$

In view of the characteristics of the standard deviation, the proposed method abandons the pixel block selection strategy of the PVO algorithm, and uses the standard deviation to measure the block complexity.

The embedding efficiency curve of proposed method is shown in Figure 1. Obviously, when the threshold parameter takes a small value, the proposed method obtains a high embedding efficiency, and the embedding efficiency is rapidly reduced with the increasing threshold parameters. The above indicates that the pixel block selection strategy used in the proposed method can effectively distinguish the smooth block and the complex block.

4. **Proposed method.** In this section, a higher efficiency reversible data hiding scheme based on PVO (HEPVO) is introduced.

4.1. **Target pixel block standard deviation prediction.** When the secret information is embedded, some pixels are changed, and the standard deviation of the pixel block is also changed. Because the complexity of target pixel block is near to its neighbor, the standard deviation of the target pixel block is predicted by its neighbor pixel blocks A, B, C (as shown in Figure 2).

The standard deviation of the target pixel block is computed according to

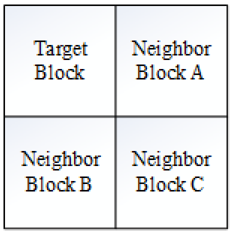

FIGURE 2. Threshold - embedding efficiency

$$\sigma = a\sigma_A + b\sigma_B + c\sigma_C \tag{8}$$

where σ_A, σ_B, σ_C is the standard deviation of pixel block A, B, C, respectively. In the proposed method, the value of the coefficient row vector (a, b, c) is (0.37, 0.37, 0.26).

4.2. **Data embedding process.** In the process of embedding data, some pixels may overflow. Overflow processing method is described in literature [24] and it is no longer detailed here. In this paper, the cover image has been preprocessed.

The cover image is divided into non-overlapped blocks first. Each block contains $n_1 \times n_2$ pixels. To improve the prediction accuracy is an important aspect of improving the performance of the reversible data hiding method based on PEE. In the proposed method, pixel block standard deviation is used to determine whether a pixel block could be embedded secret information. If the standard deviation of target pixel block is less than the threshold T, then the pixel block could be embedded secret information. Otherwise, it is a complex pixel block and skip it. Scan the image in order from left to right, from top to bottom.

The 4.1 section describes how to predict the standard deviation of target pixel block. In general, better image quality can be obtained when the threshold is smaller, but the embedding capacity is limited at the same time. In the actual embedding process, the threshold value should be adjusted according to the embedding capacity.

The block which of the standard deviation is less than the threshold can be used to embed secret data. In the process of data embedding, the PVO method is used. Sort the pixel in the block firstly, then use the second maximum/minimum pixel to predict the maximum/minimum pixel, as shown in formula (2). The maximum/minimum pixel is modified or remain unchanged according to the prediction error. If the prediction error is 0, do nothing. If the prediction error is 1 or -1, one bit could be embedded. Otherwise if the prediction error is more or less than 1 or -1, maximum/minimum pixel add 1 or -1.

The location of the last pixel block is recorded and sent to the recipient when the secret data is embedded completely.

The data embedding process is summarized as follows:

Input: Cover image sized (W, H), Secret message $M(m_1 m_2 ... m_{LN})$.

Output: Stego image, parameter *pos*.

Step1: The cover image is divided into non-overlapped blocks, each block contains $n_1 \times n_2$ pixels. Pixel block is represented by B(i), $1 \geq i \geq (W \times H)/(n_1 \times n_2)$.

Step2: Set $i = 1$.

Step3: Read the pixel block B(i), and predict its standard deviation.

Step4: If the standard deviation of the pixel block B(i) is larger than the threshold T, then go to Step5. Otherwise the secret data is embedded. Here, the data embedding process of the PVO method is used.

Step5: Set $i = i+1$ and go to Step3.

The parameter *pos* is recorded and sent to the recipient, where the *pos* is the location of the last pixel block.

4.3. **Data extraction process.** The stego image is divided into non-overlapped blocks first. Then scan the image in order from right to left, from bottom to top. The start position is the last pixel block position when the secret data is embedded completely. After the data extraction is finished, the bit sequence reversed in horizontal is the original secret data sequence.

The data extraction process is summarized as follows:

Input: Stego image, parameter pos.

Output: Cover image, Secret message.

Step1: The cover image is divided into non-overlapped blocks, each block contains $n_1 \times n_2$ pixels. Pixel block is represented by B(i), $1 \geq i \geq (W \times H)/(n_1 \times n_2)$.

Step2: Set $i = pos$.

Step3: Read the pixel block B(i), and predict its standard deviation.

Step4: If the standard deviation of the pixel block B(i) is larger than the threshold T, then go to Step5. Otherwise calculate prediction error. The data extraction process of the PVO method is used to extract the secret information and restore the original pixel value.

Step5: Set $i = i{-}1$ and go to Step3.

(a)Lena (b)Baboon (c)Boat

(d)F16 (e)Goldhill (f)Peppers

FIGURE 3. Test images

5. **Experimental results.** Six grayscale images sized 512×512 shown in Figure 3 are used as the cover images, namely Lena, Baboon, Boat, F16, Goldhill and peppers. The test images are from USC-SIPI database. The proposed method is compared with PVO

and IPVO method. All methods are implemented using MATLAB R2013a for simulation. The experiment tests the performance of the proposed method in terms of embedding efficiency and visual quality of stego images.

The cover image is divided into 2×2 size block in the proposed and the contrast method. The threshold T starts from the minimum value and adaptively increases when the embedding capacity is not satisfied. The embedding capacity is increased with a step size of 1000 bit. In the process of data embedding, the test image is scanned from left to right and from top to bottom.

5.1. **Embedding efficiency.** The experimental results of the embedding efficiency are shown in Figure 4. The PVO method and the improved PVO method are chosen as the comparison method. According to the experimental results, the embedding efficiency of the proposed method is obviously better than the others

In Figure 4 (a), the embedding efficiency of the proposed method is greater than the others when the embedding capacity is less than 27000 bits. The embedding efficiency of PVO method do not decrease as the embedding capacity increases because the lower right region of Lena image is smoother. The embedding efficiency curve of IPVO method appeared zigzag shape. This is because the change of threshold T increased by 1 has a great influence on the embedding efficiency. In Figure 4 (b), the embedding efficiency of the three methods is generally declining, and it is more stable. Similar to Figure 4 (a), the embedding efficiency of comparison method decreases slowly as the embedding capacity increases in Figure 4 (c). The sawtooth phenomenon is obvious at low embedding capacity. The sawtooth phenomenon of PVO method is obvious in Figure 4 (d) too. Although the test image F16 is relatively smooth, there are still complex blocks inside. The upper-left corner of the image F16 is complex, and the right side of the area is smoother, that is the reason why the embedding efficiency of PVO method increases when the embedding capacity is low. The IPVO method has better performance in the smooth region. The upper part of the F16 image is smoother, and the embedding efficiency increases when the embedding capacity grows. In Figure 4 (e), the embedding efficiency of the PVO and IPVO methods is higher when the embedding capacity is little. That is because the area at the top of the Goldhill image is relatively smooth. In this case the embedding efficiency of the IPVO method is better than the proposed method. However, with the increase of embedding capacity, the embedding efficiency of PVO and IPVO method is reduced rapidly. The embedding efficiency of the proposed method decreases slowly. In Figure 4 (f), the embedding efficiency curve is similar to that in Figure 4 (a).

The reason for the appearance of the sawtooth phenomenon is that the pixel block selection strategy has disadvantages. For example, there is a pixel block A, the pixel value in ascending order is $(a\ b\ c\ d)$. In PVO and IPVO method, the complexity of a pixel block depends on the difference between b and c, and the difference between a and b, c and d are not considered. With this strategy, a pixel block is treated as smooth pixel block, in which the difference between b and c is small while the difference between a and b, c and d are large. It can be seen that the pixel block selection strategy is invalid in this case. This problem may be avoided by using standard deviation. The results in Figure 4 show that the embedding efficiency of PVO and IPVO is seriously affected by the natural image texture distribution while the embedding efficiency of the proposed method is not affected.

5.2. **Image quality.** From Figure 5, it is clearly that the proposed method is better than the PVO and IPVO methods in terms of image quality. The image quality of PVO and IPVO method is better than ours in Figure 5 (e). The main reason is that there is a narrow smooth region at the top of the image Goldhill, which has high embedding

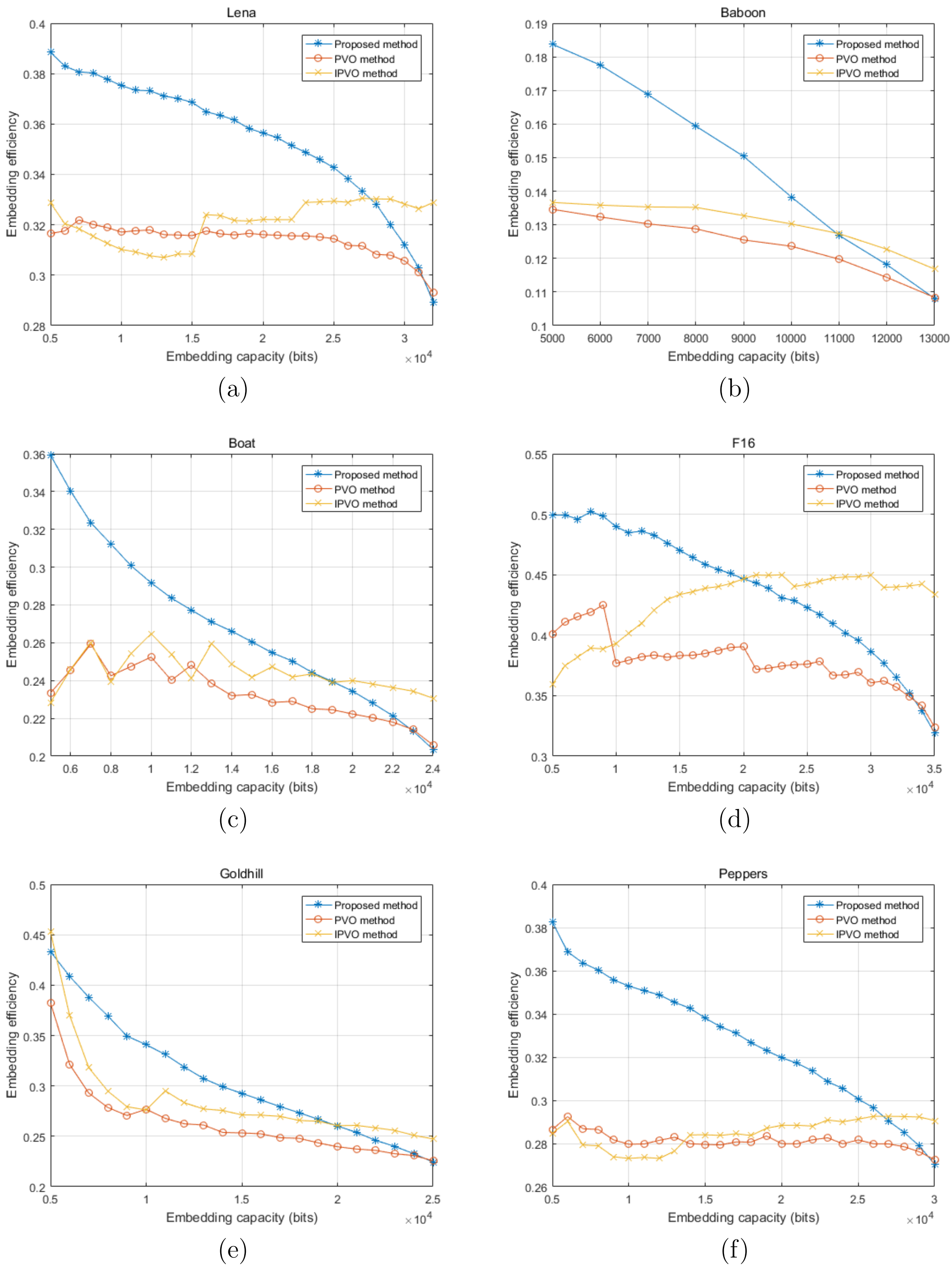

FIGURE 4. Embedding efficiency comparison between our method and two methods of Li et al. [18], Peng et al. [20].

efficiency for PVO and IPVO method. The image quality of three methods is shown in table 1 when they have the embedding capacity of 10000 bits. Compared with PVO and IPVO, the average PSNR of proposed method is increased by 1.3083 and 1.2619dB respectively.

TABLE 1. Comparison of PSNR (in dB) between our method and two methods of Li et al. [18], Peng et al. [20] for a capacity of 10,000 bits.

Test images	Lena	Baboon	Boat	F16	Goldhill	Peppers	Average
PVO	58.3143	53.5404	56.4574	58.7884	57.7598	57.7039	57.0940
IPVO	58.3526	53.6732	56.3451	58.6654	58.2425	57.5636	57.1404
Proposed	59.2719	54.0768	57.8052	61.6544	58.7291	58.8767	58.4023

6. **Conclusion.** The PVO method has attracted much attention due to its high image quality since it published. There are many RDH scheme based on PVO but few have analyzed the performance of the algorithm. In this paper, we analyze the PVO performance and point out that the pixel block selection strategy has defects. In the proposed scheme, the standard deviation is used to measure the block complexity. The standard deviation of the target pixel block is predicted by its neighbor pixel blocks. In the experiment part, we use MATLAB to simulate PVO, IPVO and the proposed method. The proposed method is compared with the original method from two aspects of embedding efficiency and image quality. The results show that the proposed method has better performance. Most of the information hiding methods based on PVO inherit the pixel block selection strategy of PVO method. We can predict that their embedding efficiency and image quality could be improved after the pixel block selection strategy improved.

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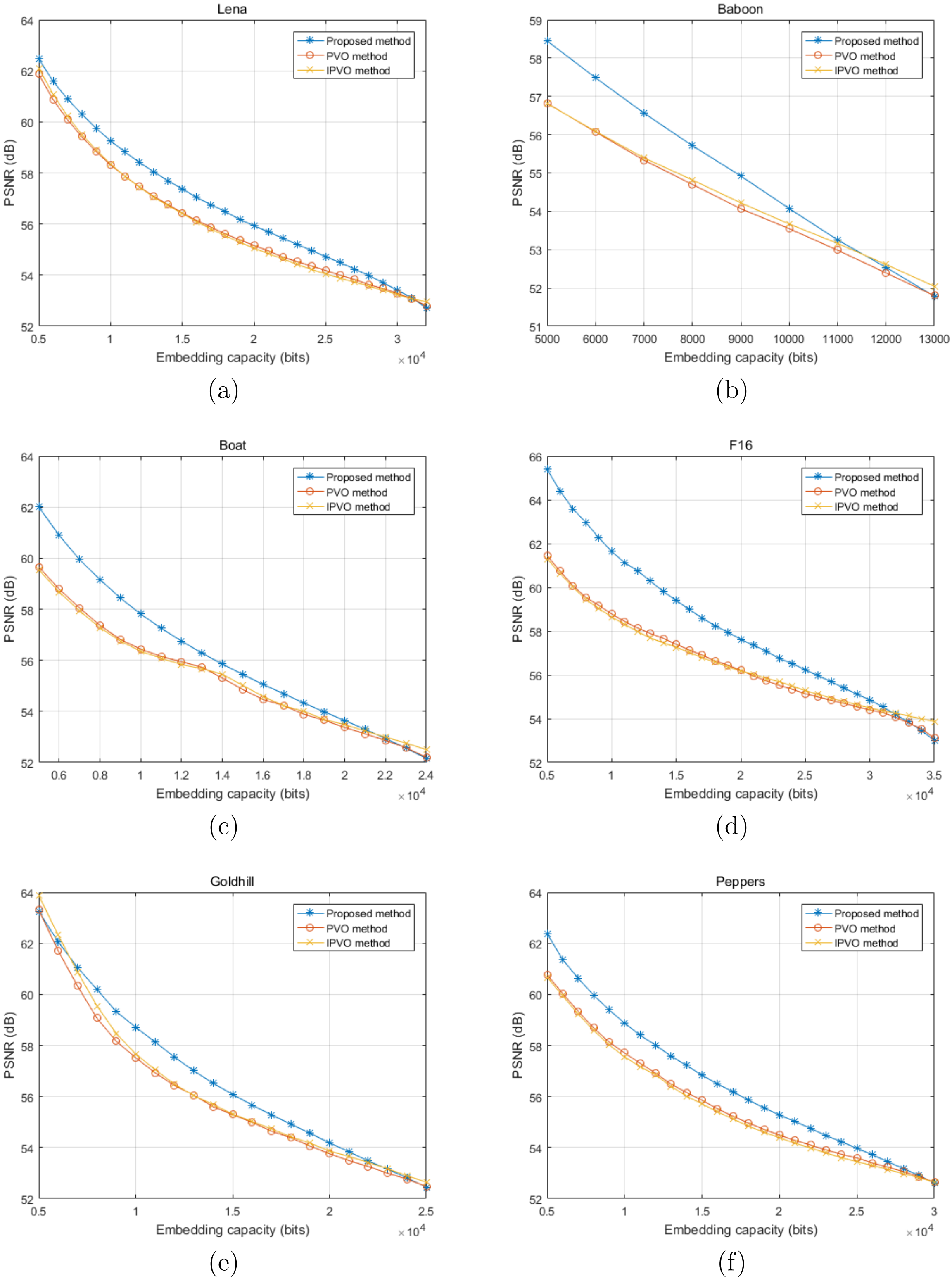

FIGURE 5. Image quality comparison between our method and two methods of Li et al. [18], Peng et al. [20].

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