An Improved LSB Steganography Method Using Pixel Difference Threshold

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Abstract

Least Significant Bit (LSB) substitution is one of the simplest and most widely used image steganography techniques due to its low computational complexity. However, conventional LSB embedding modifies all pixels uniformly, which often leads to unnecessary visual distortion and noticeable statistical artifacts, especially in smooth image regions. In this paper, we propose a simple content-adaptive LSB steganography scheme based on pixel difference thresholding. The proposed method selectively embeds secret bits only in pixel locations with sufficiently large inter-pixel differences. By avoiding embedding in smooth areas, the method effectively improves imperceptibility and reduces histogram distortion. Experimental results demonstrate that, compared with conventional LSB embedding, the proposed scheme achieves higher PSNR under the same embedding depth, while maintaining perfect extraction accuracy and low computational complexity.

Ⅰ. INTRODUCTION

steganography aims to conceal secret information within a digital image while minimizing perceptual and statistical distortions. Among various steganographic techniques, Least Significant Bit (LSB) substitution remains one of the most popular approaches due to its simplicity and high embedding capacity [1]. In conventional LSB-based methods, secret bits are uniformly embedded into the least significant bits of all pixels. Although this strategy offers a large payload capacity, it ignores image content characteristics and often introduces unnecessary distortions in smooth regions, making the stego-image more vulnerable to visual inspection and statistical analysis.

To address this issue, content-adaptive steganography has been widely studied, where embedding decisions are guided by local image characteristics. Motivated by this idea, we propose a simple yet effective improvement to conventional LSB embedding. The proposed method utilizes inter-pixel differences to estimate local image complexity and selectively embeds secret data only in regions with large pixel differences. Unlike complex adaptive schemes, the proposed method introduces minimal additional computation while achieving a better trade-off between embedding capacity and imperceptibility. The main contributions of this paper are as follows.

- A simple content-adaptive LSB embedding scheme is proposed by incorporating pixel difference thresholding, enabling selective data hiding in visually complex regions while preserving smooth areas.
- A comprehensive experimental evaluation is conducted to analyze the trade-off between embedding capacity and imperceptibility under different embedding depths, threshold values, and payload ratios. The results demonstrate that the proposed method significantly improves PSNR and reduces histogram distortion compared with conventional LSB embedding.

Ⅱ. RELATED WORK

Traditional LSB substitution directly replaces the least significant bits of image pixels with secret data, resulting in straightforward implementation but poor resistance to steganalysis. Numerous improvements have been proposed, including random embedding, edge-based methods, and pixel-value differencing (PVD) techniques. PVD-based methods embed data according to the difference between neighboring pixels, allowing higher capacity in textured regions and lower capacity in smooth areas [2-3]. However, many PVD schemes require complex range tables or introduce noticeable pixel modifications [4].

In contrast, our approach adopts a simplified pixel-difference-based strategy to guide LSB embedding. By introducing a single threshold parameter, the method preserves the simplicity of conventional LSB while incorporating basic content adaptivity.

Ⅲ. PROPOSED METHOD

3.1 Conventional k-LSB Embedding

Given a grayscale image $I = \{x_i\}$, conventional k-LSB embedding modifies each pixel as follows:

$$x_i' = x_i - (x_i \bmod 2^k) + s_i, \quad (1)$$

where s_i represents k secret bits. This method embeds data uniformly across the entire image without considering local image structure.

3.2 Pixel Difference Threshold-Based LSB Embedding

To incorporate content adaptivity, we compute the absolute difference between adjacent pixels:

$$d_i = |x_i - x_{i+1}|, \quad (2)$$

A pixel is selected for embedding only if its difference satisfies:

$$d_i \geq T, \quad (3)$$

where T is a predefined threshold. The embedding rule is defined as:

$$x_i = \begin{cases} x_i - (x_i \bmod 2^k) + s_j, & d_i \geq T \\ x_i, & d_i < T \end{cases} \quad (4)$$

Pixels located in smooth regions (small d_i) remain unchanged, while pixels in complex regions are used for data hiding.

3.3 Conventional k-LSB Embedding

The extraction process follows the same pixel selection rule based on the threshold T. Secret bits are retrieved from the k least significant bits of selected pixels, ensuring lossless extraction as long as the threshold and embedding depth are known.

3.4 Computational Complexity

Both conventional LSB and the proposed method require a single pass over the image pixels, resulting in linear time complexity O(N), where N is the number of pixels. Therefore, the proposed method introduces no additional computational burden.

IV. EXPERIMENTAL

In this section, we evaluate the performance of the proposed DT-LSB steganography scheme and compare it with conventional LSB embedding. All experiments were conducted on standard grayscale test images. The performance is evaluated in terms of embedding payload, peak signal-to-noise ratio (PSNR), extraction accuracy, and histogram distortion.

4.1 Comparison with Conventional LSB

We first compare the proposed DT-LSB method with conventional LSB embedding under different LSB depths k. The value of k is set to 1, 2, 3, and 4, respectively. For each setting, both methods embed secret data using the same LSB depth, and the extraction accuracy is evaluated accordingly. The quantitative comparison results are summarized in Table 1. As shown in the table, conventional LSB achieves higher embedding payload due to uniform embedding over all pixels. However, the proposed DT-LSB method consistently achieves significantly higher PSNR for all tested values of k, while maintaining perfect extraction accuracy.

Table 1: Performance Comparison on Lena (T = 10)

Methods	LSB	Payload (bits)	PSNR (dB)
LSB	1	262,144	51.14
DT-LSB	1	40,263	**59.30**
LSB	2	524,288	44.26
DT-LSB	2	80,526	**52.39**
LSB	3	786,432	37.85
DT-LSB	3	120,789	**46.02**
LSB	4	1,048,576	31.82
DT-LSB	4	161,052	**39.97**

4.2 Threshold Analysis

To analyze the effect of the pixel difference threshold T, we conduct experiments by varying T while keeping the LSB depth fixed at k=1. The threshold values are set to T=5,10,15 and 20.

The experimental results are illustrated in Fig. 1, which shows the relationship between the threshold value, embedding payload, and PSNR. As the threshold T increases, fewer pixels satisfy the embedding condition, leading to a reduced payload. At the same time, the PSNR of the stego-image increases noticeably. This behavior confirms that the threshold parameter provides an effective and flexible mechanism to control the trade-off between embedding capacity and visual quality.

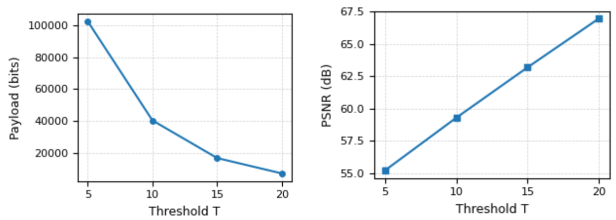

Fig1, The relationship between the threshold value, embedding payload, and PSNR.

4.3 Payload-Imperceptibility Trade-off

In this experiment, we further investigate the relationship between embedding payload and imperceptibility. The threshold is fixed at T=10, and the actual embedded payload is varied by selecting different payload ratios relative to the maximum available capacity.

The PSNR values under different payload ratios are presented in Fig. 2. It can be observed that the PSNR decreases gradually as the payload ratio increases. Importantly, the degradation in visual quality is smooth rather than abrupt, indicating that the proposed method maintains stable imperceptibility over a wide range of embedding rates.

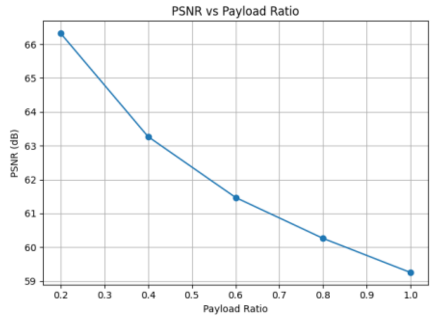

Fig 2, The PSNR values under different payload ratios.

V. CONCLUSION

This paper presented a simple content-adaptive LSB steganography scheme based on pixel difference thresholding. By selectively embedding secret data in regions with high inter-pixel differences, the proposed method achieves a better balance between payload capacity and imperceptibility. Experimental results demonstrate improved visual quality and reduced histogram distortion compared with traditional LSB methods. Due to its simplicity and effectiveness, the proposed scheme is suitable for practical steganographic applications with limited computational resources.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government(MSIT) (2022R1A2C1011862).

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