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High-fidelity reversible data hiding scheme based on multi-predictor sorting and selecting mechanism ☆

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ABSTRACT

Reversible data hiding can completely recover the cover image without any distortion after the secret data is retrieved. In this paper, a new high-fidelity reversible data hiding scheme is proposed using the prediction-error histogram modification technique. A multi-predictor sorting and selecting mechanism is proposed to select an optimum predictor from a set of predictors. Then a smaller prediction-error is obtained to embed the secret data using the prediction-error histogram modification technique. Since the multi-predictor sorting and selecting mechanism can utilize the advantage of multi-predictor and information of current predicted pixel to obtain a more accurate prediction value, our proposed scheme can introduce less image distortion at the same embedding payload. Experimental results demonstrate that our proposed scheme outperforms the similar reversible data hiding schemes.

1. Introduction

Data hiding is a technique to embed the secret data into a cover digital media such as text, audio, image and video and the main purpose of data hiding is to conceal secret data into the cover media to avoid the attention of attackers [1,2]. Reversible data hiding is a special class of data hiding which retrieves the secret data while recovers the cover media without any distortion. Data hiding in digital images can be classified into three domains: the spatial domain [3–17], the frequency domain [18,19] and the compressed domain [20,21].

Many reversible data hiding schemes in the spatial domain have been proposed in the recent years. The early reversible data hiding schemes are mainly based on lossless compression [3,4]. These schemes losslessly compress certain features of cover image to save space for embedding secret data and usually provide a low embedding payload and may lead to severe degradation in image quality. Later on, more efficient schemes based on difference expansion (DE) and histogram modification technique have been proposed. The DE technique is firstly proposed by Tian in 2003 where the pixel difference is expanded to embed data [5]. Tian's scheme can provide a much higher embedding payload while keeping a low distortion compared with the compression-based reversible data hiding schemes. The histogram modification technique is firstly proposed by Ni et al. in 2006 where the peak points of image histogram are modified to embed the secret data [6]. It achieves a high visual quality of stego image but has a low embedding payload. Recently, many prediction-based reversible data hiding schemes, which are the extensions of DE and histogram modification technique, have been proposed [7–17]. The basic idea of the prediction-based reversible data hiding schemes is that the prediction process is firstly conducted to generate the prediction-error between the pixel value and pixel prediction value, which is used to embed the secret data using DE or histogram modification technique. In the prediction-based reversible data hiding schemes, a smaller prediction-error leads to a better visual quality of stego image and higher embedding payload. However, the prediction-accuracy cannot be guaranteed because only one predictor is employed in reported prediction-based reversible data hiding schemes [7–17]. Therefore, this paper proposes a new high-fidelity reversible data hiding scheme based on multi-predictor sorting and selecting mechanism. In our scheme, the multi-predictor sorting and selecting mechanism can utilize the advantage of multi-predictor and information of current predicted pixel to obtain a more accurate prediction value. As a result, a smaller prediction-error can be obtained to embed the secret data using the prediction-error histogram modification technique. Moreover, the pixel selection strategy inspired by the previous works [12,13] is also

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introduced to further improve the embedding performance. Experimental results demonstrate that our proposed scheme outperforms the previous similar reversible data hiding schemes [8,11–15].

The rest of paper is organized as follows. Section 2 introduces the basic idea of prediction-error histogram modification technique and predictors. The detail of proposed scheme is presented in Section 3. The experimental results are shown in Sections 4 and 5 gives our conclusions.

2. Related work

In this section, we will briefly describe the basic idea of reversible data hiding scheme based on prediction-error histogram modification technique and review four common predictors.

2.1. The prediction-error histogram modification technique

In 2009, Hong et al. proposed a reversible data hiding technique based on modification of prediction-error [11]. In Hong et al.'s scheme [11], the prediction-error is calculated from the neighborhood of the pixel and then the prediction-error is modified to embed the secret data. The basic idea of the prediction-error histogram modification technique is summed up as follows.

In the embedding process, for each pixel, an integer prediction value $\hat{x}$ is obtained using a predictor. Then the prediction-error e is calculated as $e = x - \hat{x}$. Following, the corresponding prediction-error histogram $h(e)$ is obtained by calculating the frequencies of prediction-errors. Usually, prediction-error histogram $h(e)$ is a Laplacian-like distribution with the highest bin at zero or close to zero. The prediction-error histogram $h(e)$ is divided into two non-overlapping parts: non-negative part $h(e_+)$ and negative part $h(e_-)$, where $e_+ \in [0, 255]$ and $e_- \in [-255, -1]$. Then two peak points P_+ and P_- are obtained. Usually, the peak point $P_+ = 0$ and $P_- = -1$. Then, each prediction-error e is modified according to the prediction-error histogram modification technique as follows.

$$e' = \begin{cases} e+1, & e \in [1, 255] \\ e+sd, & e = 0 \\ e-sd, & e = -1 \\ e-1, & e \in [-255, -2] \end{cases} \tag{1}$$

where sd is 1-bit secret data. Then the pixel value in stego image x' is calculated as $x' = \hat{x} + e'$ and the stego image is obtained.

In the extracting process, for each pixel x' in the stego image, the integer prediction value $\hat{x}$ is obtained using the same predictor and the same prediction content. Then the stego prediction-error is calculated as $e' = x' - \hat{x}$ and the recovery of pixels and secret data extraction are conducted as follows.

$$e = \begin{cases} e'-1, & e' \in [2, 255] \\ 0, & e' \in [0, 1] \\ -1, & e' \in [-2, -1] \\ e'+1, & e' \in [-255, -3] \end{cases} \tag{2}$$

$$sd = \begin{cases} e'-e, & e' \in [0, 1] \\ e-e', & e' \in [-2, -1] \end{cases} \tag{3}$$

$$x = \hat{x} + e \tag{4}$$

After all the pixels in the stego image are processed, the secret data is extracted and the cover image is recovered.

2.2. Four common predictors

The median edge detector (MED) [22] and the gradient adjusted prediction (GAP) [23] are the widely-used predictors in the data hiding schemes [7,8,11,13]. In this section, we briefly describe the predictors of MED and GAP. An improved version of MED, proposed by Jiang et al. in 2000 [24], (shorted as Jiang et al.'s predictor) is introduced in this section. An improved version of GAP which is the accurate gradient selective prediction (AGSP), proposed by Tang and Kamata in 2006 [25], is also introduced in this section.

2.2.1. Median edge detector (MED)

The MED predictor [22] is a low-complexity predictor which operates on the three neighboring pixels n, w and nw of the current pixel x shown in Fig. 1. The prediction value $\hat{x}$ is calculated as follows.

$$\hat{x} = \begin{cases} \min(n, w), & \textit{if } nw \geqslant \max(n, w) \\ \max(n, w), & \textit{if } nw \leqslant \min(n, w) \\ n + w - nw, & \textit{otherwise} \end{cases} \tag{5}$$

2.2.2. Gradient adjusted prediction (GAP)

The GAP predictor [23] operates on the seven neighboring pixels n, w, nw, ne, ww, nn and nne of the current pixel x shown in Fig. 1. The prediction value $\hat{x}$ is calculated as follows.

$$\hat{x} = \begin{cases} w, & \textit{if } d_v - d_h \in (80, +\infty) \\ (\hat{x}' + w)/2, & \textit{if } d_v - d_h \in (32, 80] \\ (3\hat{x}' + w)/4, & \textit{if } d_v - d_h \in (8, 32] \\ \hat{x}', & \textit{if } d_v - d_h \in [-8, 8] \\ (3\hat{x}' + n)/4, & \textit{if } d_v - d_h \in [-32, -8) \\ (\hat{x}' + n)/2, & \textit{if } d_v - d_h \in [-80, -32) \\ n, & \textit{if } d_v - d_h \in (-\infty, -80) \end{cases} \tag{6}$$

where $\hat{x}' = (n + w)/2 + (ne - nw)/4$, $d_v = |w - nw| + |n - nn| + |ne - nne|$ and $d_h = |w - ww| + |n - nw| + |n - ne|$. Following, the integer prediction value $\hat{x}$ is obtained as follows.

$$\hat{x} = round(\hat{x}) \tag{7}$$

where the function $round(\bullet)$ rounds the element to its nearest integer.

2.2.3. Jiang et al.'s predictor

The Jiang et al.'s predictor [24] operates on the four neighboring pixels n, w, nw and ne of the current pixel x shown in Fig. 1. The prediction value $\hat{x}$ is calculated as follows.

```
if nw ⩾ max(n, w)
{
  if (nw − min(n, w) > 10 & nw < n & w − n ⩾ 5)
    x̂ = (nw + min(n, w))/2
  else
    x̂ = min(n, w)
  end
}
elseif nw ⩽ min(n, w)
{
  if (10 ⩽ nw − n ⩽ 50 & |n − w| ⩽ 10 & min (n, w) − nw ⩾ 5)
    x̂ = (nw + max(n, w))/2
  else
    x̂ = max(n, w)
  end
}
else
  x̂ = n + w − nw
end
```

Then the integer prediction value $\hat{x}$ is obtained using Eq. (7).