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Asymmetric-histogram based reversible information hiding scheme using edge sensitivity detection

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ABSTRACT

Histogram shifting is a common reversible data hiding method that can effectively embed secret information with the distribution of image pixel value (or error). However, the image quality of histogram shifting depends on the distance between the zero point and peak point, and a long distance may cause serious image distortion. This study employs an edge sensitivity analysis method established by Lukac et al. to reduce the prediction error and integrates the asymmetric-histogram shifting established by Chen et al. to restore the error value to a place near the original image pixel value in the second shift. The results show that the pixel complementary mechanism has better image quality in multi-level embedding, especially for smooth images. Images with different characteristics will have better information capacity and image quality through two predictive methods.

1. Introduction

Information hiding aims to conceal secret information in the process of transmission by hiding it in covert media. Enhancing the overall information embedding ability in high security and in the absence of notice has become a major challenge (Lou et al., 2013).

Reversible data hiding (RDH) is a very important technology in the field of information hiding. It aims at restoring the original state of the image for re-using after extracting the secret information from the camouflage image (Tsai et al., 2005). The technology is mostly used in high-value images such as medical images, military maps, and art (Wen et al., 2012). However, a lot of hiding capacity would be sacrificed to restore the image completely; therefore, enhancing hiding capacity and retaining the characteristics of image restoration is the top priority of RDH research.

In recent years, RDH technology can be divided into two directions. The diagram of recent RDH technologies is shown in Fig. 1. One of them is difference expansion, which uses the difference between pixels (or between original pixel value and predicted pixel value) to embed secret information, and multiply the difference several times. For example, Tian put forward a difference expansion prototype in 2003, which doubles the difference between 2 adjacent pixels and embeds 1 bit of secret information (Tian, 2003). Alatter expanded Tian's method in 2004 by hiding 3 bits of secret information in two-fold difference through the difference between 4 neighboring pixels (Alattar, 2004). Lou et al. put forward a multi-level information hiding technology in 2009, which can achieve multi-embedding with Tian's method after reducing the difference value, with 2 horizontal pixels in an odd-numbered round and 2 vertical pixels in an even-numbered round (Lou et al., 2009). Qin et al. embedded secret information in two-fold difference values in 2012 by calculating the average of three adjacent pixels and determining the difference with the original pixel and the average (Qin et al., 2012). Li et al. applied difference expansion to color images in 2013 by embedding secret information with Tian's method after splitting color images into RGB color tables and choosing a color table for prediction according to the threshold (Li et al., 2013). In 2013, Ou et al. managed to double and embed the errors meeting the threshold after self-adaptive adjustment on the threshold according to the length of secret information for embedding by taking partial differential equation (PDE) as a predictor to improve the accuracy (Ou et al., 2013). From the above, if the difference is too large, the image quality will be severely distorted after multiple expansions; on the contrary, if the difference is too small, the difference is relatively small after expansions and the influence on image quality will significantly decrease.

The other RDH technology is histogram-shift based. It embeds secret information in frequent values by using statistical analysis on pixel (or error value) distribution. For example, the histogram shifting concept established by Ni in 2006 enables the analysis on pixel distribution in histograms and the embedding of secret information in frequent pixels (Ni et al., 2006). The asymmetric-histogram

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0164-1212/

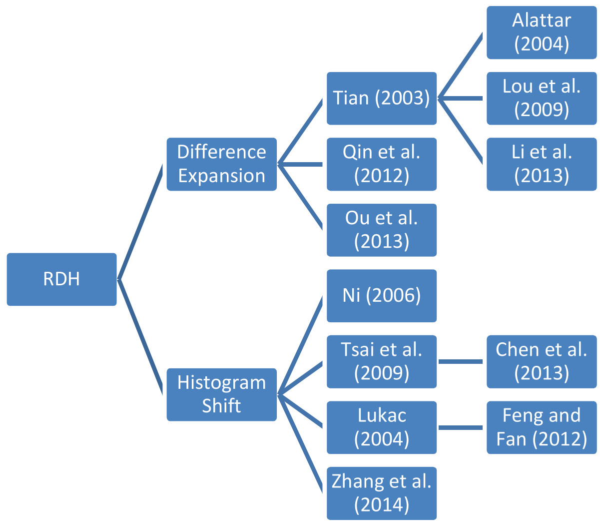


Fig. 1. The diagram of recent RDH technologies.

shifting put forward by Tsai et al. in 2009 manages to embed secret information in frequent errors by calculating prediction errors with the linear prediction method and building a histogram for negative and positive error values respectively (Tsai et al., 2009). Chen et al. made improvements on the method of Tsai et al. in 2013, which establish histograms respectively with the maximum and minimum error values in the same block, and shift the pixels of the maximum error histogram to left and those of the minimum error histogram to right by adopting the complementary pixel concept to improve the image quality after embedding (Chen et al., 2013). Feng and Fan enhanced the accuracy of prediction in 2012 with the Lukac prediction method, sorted out the frequency of occurrence of each prediction error, and finally embedded secret information in the peak point (Feng and Fan, 2012). Zhang et al. established a new method by combining encryption with histogram shifting in 2014, which makes predictions with the average of neighboring pixels and analyzes the prediction error histogram, and embeds secret information between the peak point and secondary peak point after finding them in the histogram (Zhang et al., 2014).

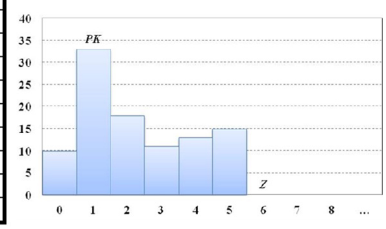
From the above, the hiding capacity of histogram shifting depends on the peak point value. The more peak points, the more locations for information embedding, and vice versa. And the peak point value of error histogram changes with the accuracy of prediction method. Therefore, improving the accuracy of prediction poses a great challenge to the error value histogram technology.

The edge sensitivity analysis put forward by Lukac et al. can effectively utilize the relevance of adjacent pixels to enhance prediction accuracy. Feng and Fan extended Lukac's method and enhanced the accuracy of prediction regarding complex images. Therefore, this study combines the two prediction methods to enhance hiding capacity and image quality through error value statistics based on the asymmetric-histogram shifting established by Chen et al.

This study describes the entire research process sequentially: Section 2 details the histogram shifting (Section 2.1) and the Lukac prediction method extended by Feng and Fan (Section 2.2). Section 3 shows the entire research process and examples. Section 4 discusses the impact of the way to establish an error value histogram on overall hiding capacity and image quality, and compares it in Section 4.2 with the experimental results of other scholars. Finally, Section 5 presents the conclusion.

	0	1	2	3	4	5	6	7	8	9
0	5	5	0	5	1	5	4	3	1	1
1	0	0	1	3	1	5	5	4	1	1
2	1	5	5	5	2	3	4	1	2	2
3	1	1	1	2	1	0	0	1	0	2
4	1	1	1	1	3	1	1	2	1	1
5	1	4	2	4	2	4	4	3	1	5
6	1	1	4	3	4	2	2	0	0	2
7	3	1	4	1	2	4	3	1	1	5
8	2	2	5	0	2	4	5	4	5	3
9	1	5	2	0	2	3	2	1	1	3

(a) Original pixel $x_{(i,j)}$



(b) Histogram table

Fig. 2. Example of histogram shifting.

2. Literature review

2.1. Histogram shifting

Histogram shifting is the RDH technology put forward by Ni et al. in 2006 (Ni et al., 2006). It generates a histogram table based on statistical distribution of pixels on the entire image, with the formula shown below,

$$H(x_{(i,j)}) = H(x_{(i,j)}) + 1, \tag{1}$$

where $H(.)$ is the number of occurrences of pixel values and $x_{(i,j)}$ is the original pixel value. When the same pixel value appears, the number of occurrences of the pixel value $x_{(i,j)}$ will increase progressively. The work, after the collection of all the pixel values, is to look for the peak points that frequently appear and the zero points that have never appeared and to modify the histogram through the following conditions:

$$x'_{(i,j)} = \begin{cases} x_{(i,j)} + 1, & \text{if PK} < x_{(i,j)} < Z, \\ x_{(i,j)} + s, & \text{if } x_{(i,j)} = \text{PK}, \\ x_{(i,j)}, & \text{otherwise}, \end{cases} \tag{2}$$

where $x'_{(i,j)}$ is the camouflage pixel value, PK is the peak point, Z is the zero point, and s is the secret information. If the pixel value $x_{(i,j)}$ is between PK and Z, the pixel value will be shifted 1 unit to the right; if the pixel value $x_{(i,j)}$ is equal to PK, secret information s can be embedded in the pixel position; if the pixel value $x_{(i,j)}$ is not between PK and Z or equal to PK, the pixel value will remain unchanged.

Taking Fig. 2 for example, after the analysis of the pixel values in Fig. 2(a) (as shown in Fig. 2(b)), the peak point is PK = 1, and the zero point is $Z = 6$. Then the conditional formula (2) is used to determine the shift and embedding condition of each pixel value. Take $x_{(0,4)} = 1$ for example, the pixel value $x_{(0,4)}$ is equal to PK, it means the pixel value can be embedded with secret information; assuming secret information $s = 1$, then $x'_{(0.4)} = x_{(0.4)} + s = 1 + 1 = 2$, and so on and so forth. All the secret information will be embedded and camouflage images will be generated.

However, the histogram shift with original pixel values would limit the embedding capacity of the whole image, because the image color distribution is generally not consistent. When the image features are complex, there will be decreases in peak point and thus in hiding capacity.

Therefore, histogram shifting is combined with the prediction technique to enhance the overall information embedding capacity by predicting the error value histogram. The error value histogram established by Tsai et al. in 2009 with prediction errors (Tsai et al., 2009) divided an image into blocks of $v \times v$, and used one pixel position $x_{(r,q)}$ as basic pixel for this block, then produced error values in a way of linear prediction. Its formula is as follows:

$$e_{(i,j)} = x_{(i,j)} - x_{(r,q)}, \quad \text{when } i \neq r \text{ and } j \neq q. \tag{3}$$

In the equation, $e_{(i,j)}$ is the error value, $x_{(i,j)}$ and $x_{(r,q)}$ is the original pixel, i and j are the two-dimensional image pixel position, r and q