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A HDWT-based reversible data hiding method

Yung-Kuan Chan [a], Wen-Tang Chen [b], Shyr-Shen Yu [b,*], Yu-An Ho [b], Chwei-Shyong Tsai [a], Yen-Ping Chu [c]

[a] Department of Management Information Systems, National Chung Hsing University, Taiwan, ROC
[b] Department of Computer Science and Engineering, National Chung Hsing University, No. 250, Kuokuang Road, Taichung 402, Taiwan, ROC
[c] Department of Computer Science and Information Engineer, Tunghai University, Taiwan, ROC

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ABSTRACT

This paper presents a reversible data hiding method which provides a high payload and a high stego-image quality. The proposed method transforms a spatial domain cover image into a frequency domain image using the Haar digital wavelet transform (HDWT) method, compresses the coefficients of the high frequency band by the Huffman (or arithmetic) coding method, and then embeds the compression data and the secret data in the high frequency band. Since the high frequency band incorporates less energy than other bands of an image, it can be exploited to carry secret data. Furthermore, the proposed method utilizes the Huffman (or arithmetic) coding method to recover the cover image without any distortion. The proposed method is simple and the experimental results show that the designed method can give a high hiding capacity with a high quality of stego-image.

1. Introduction

With the increasing popularity of the Internet and the rapid increase of bandwidth allocation, various forms of digital data can be transmitted easily and quickly. For this reason, the availability of data in digital form has increased dramatically. There are numerous advantages in the differences between digital data and traditional binary data, such as high quality, easy editing, lossless copies, and fast transfer. On the other hand, digital data are easily stolen and commandeered by unauthorized people. In order to guarantee security of data transmission on the Internet, cryptography and data hiding are two commonly used techniques.

Over the years of data transition and increased internet speed, many data hiding schemes have been proposed (Lee et al., 1999; Thien and Lin, 2003; Wang et al., 2001; Xuan et al., 2005; Xuan et al., 2002). The basic requirements of data hiding are: (1) the image quality of the stego-image should not be seriously degraded and (2) the secret data should be imperceptible. The criteria to measure the performance of a data embedding method are as follows (Tian, 2003):

(1) *Payload capacity limit*: The maximal amount of secret data that can be embedded. A good data hiding technique is capable of embedding a larger quantity of secret data in a multimedia data carrier.
(2) *Visual quality*: To decrease malicious attacks. The difference between the cover image and the stego-image should not be visually perceptible. The peak signal-to-noise rate (PSNR) (Wang et al., 2003) is usually implemented to measure the stego-image quality.

The majority of existing data hiding schemes distort the original cover image in an irreversible manner. Conversely, any destruction or distortion to the cover image is not desirable. In medical diagnosis, it is risky to use lossy reconstruction to retrieve the original image from the stego-image because high diagnostic accuracy is required. In particular, applications such as law enforcement, for legal consequences, it is critical to reverse the stego-image back to the original image without loss of data. In other applications, such as remote sensing or military imaging, there is a need for the original image to be lossless. For these reasons, it is essential to completely and accurately reverse the stego-image back to the original cover image. The techniques required to satisfy this procedure are referred to as: reversible, distortion-free, lossless, or invertible data hiding.

Recently, a number of reversible data hiding schemes have been proposed. In 2003, Honsinger et al. (2001) presented a fragile watermarking technique for image authentication. This procedure is accomplished by applying a module-256 addition function. Due to the function in this procedure, there is a salt-and-pepper noise problem on the stego-image acquired by this method. De Vleeschouwer et al. (2003) later corrected the problem of the salt-and-pepper artifact by Macq's method using a circular interpretation of bijective transformation. Still, the visible distortion and the payload capacity of the method are limited. Ni et al. (2006) offered an

* Corresponding author. Tel.: +886 4 22840497; fax: +886 4 22853869.
E-mail addresses: ykchan@nchu.edu.tw (Y.-K. Chan), s9456028@cs.nchu.edu.tw (W.-T. Chen), pyu@cs.nchu.edu.tw (S.-S. Yu), yaho@cs.nchu.edu.tw (Y.-A. Ho), tsaics@nchu.edu.tw (C.-S. Tsai), ypchu@dragon.nchu.edu.tw (Y.-P. Chu).

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improved method to enhance the stego-image quality by shifting the bin's location, based on the color histogram of an image. It is well known that histogram distribution varies dramatically from image to image. As a result, it is hard for these methods to achieve a high data embedded payload capacity with sufficient visual quality. The methods mentioned above are implemented based on the spatial domain cover image.

Tian (2003) presented a reversible hiding method by using integer wavelet transformation and pixel-pair difference expansion. In this method, two adjacent pixels can be used to conceal one secret bit. The secret information is carried in the difference between the pixel color intensities. The best hiding capacity, in using this method, is 0.5 bits/pixel. However, Tian's method needs (1) significant extra bandwidth to carry the original LSB of the differences and location map to the receiver or (2) considerable extra hiding capacity to load them. Alattar (2004) improved Tian's method by using the difference expansion of vectors, instead of pixel pair, to hide the secret message in the cover image. In this method, k pixels are used to carry $k-1$ message bits. However, with this method, extra information is required to restore the original cover image. It means the hiding ability of the method is much lower than $(k-1)/k$ bpp.

For all the above reversible data hiding schemes, not only is the image quality of the stego-image limited, but a huge amount of extra data also has to be sent to the receiver. With this extra data, the receiver can then losslessly recover the original cover image. The objective of this paper is to present a reversible data hiding method with the capability of providing a high payload while holding the stego-image with a good visual quality.

Haar digital wavelet transformation (HDWT) can transform a spatial domain image into a frequency domain image that consists of different frequency bands. The coefficients in low frequency bands describe the manifest texture of the image, while those in high frequency bands show the minute texture of the image. As a result, when the low frequency coefficients are altered, human eyes can noticeably observe the changes on the spatial domain image. Conversely, if the high frequency coefficients are altered, human eyes are less sensitive and will not observe the changes as readily. Because of this, many data hiding methods (Wang et al., 2001; Wang et al., 2003) conceal secret data by altering the high frequency coefficients.

This paper proposes a Haar discrete wavelet transformation (HDWT)-based reversible data hiding method that first transforms a spatial domain image into a HDWT-based frequency domain image and then utilizes the high frequency coefficients to conceal the secret data. In general, most high frequency coefficients are very close to zero. Based on this property, the high frequency coefficients are good for compression by the Huffman (or arithmetic) coding method (Saywood et al., 2002). As a result, only a very small amount of capacity is required to hold the compression data so that the original high frequency coefficients can be restored.

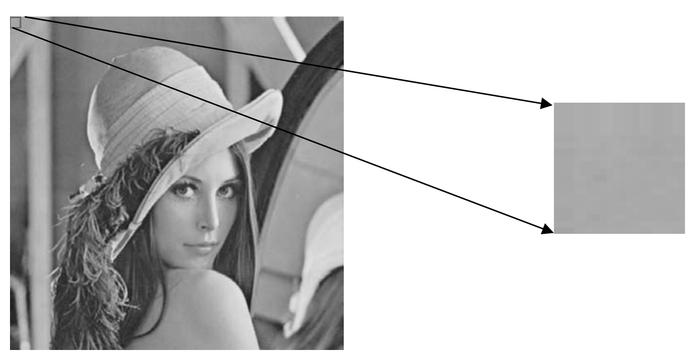
2. Preliminaries

This section will briefly review two techniques: (1) Haar discrete wavelet transformation and (2) Huffman and arithmetic coding methods. These techniques will be utilized by the HDWT-based reversible data hiding method.

2.1. Haar discrete wavelet transformation

The two-dimensional (2D) discrete wavelet transform (DWT) method is one of the most important techniques in transforming a spatial domain image into a frequency domain image. HDWT is the easiest and most commonly used method. HDWT can be implemented by two procedures: (1) horizontal operation and (2) verti-

a



b

155	156.5	157	158.5	159	0	-1.5	1	-0.5	1
155	156.5	156.75	158.5	159	0	-1.5	1	-0.5	1
153	154.5	156.75	157.25	157.75	0	-1.5	0.75	-0.25	0.75
152	153.25	156	154	156.25	0	-1.25	0	0.5	-0.75
151	153	154	154	156.25	0	-2	0	-1	1.75
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
2	2	0.25	1.25	1.25	0	0	0.25	-0.25	0.25
3	2.25	1.5	0.5	0.25	0	0.75	-0.5	1	0.25
0	0	2.5	0.5	1.25	0	0	-0.5	0.5	-0.25

Fig. 1. The decomposition of one block by one level HDWT. (a) A 10×10 block on image "Lena". (b) The coefficients of the frequency bands *LL*, *HL*, *LH*, and *HH* of the block in (a)