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Visually imperceptible image hiding scheme based on vector quantization

Shih-Chieh Shie [a,*], Shinfeng D. Lin [b], Ji-Han Jiang [a]

[a] Department of Computer Science and Information Engineering, National Formosa University, Hu-Wei, Yunlin County, Taiwan, ROC
[b] Department of Computer Science and Information Engineering, National Dong Hwa University, Hualien County, Taiwan, ROC

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ABSTRACT

A novel visually imperceptible image hiding scheme based on VQ compression and LSB modification is introduced in this article. Multiple secret images can be simultaneously and imperceptibly hid into another cover image with the same image size by the proposed scheme. In order to reduce the volume of secret images to be hid, a codebook is first generated from the secret images and these images are encoded into binary indices by the vector quantization technique. Then the compressed data of secret images are embedded into the VQ codebook used in the encoding procedure by an adaptive least-significant-bits (LSB) modification technique. For the security purpose, the slightly modified codebook is further encrypted into a meaningless data stream by the DES cryptosystem. Finally, the encrypted codebook is embedded into the cover image using the greedy LSB modification technique. Simulation results show that the proposed scheme provides a good improvement in the visual quality of the extracted secret images and the cover image at the receiver. In addition, the proposed scheme provides better hiding capacity for the cover image than earlier works.

1. Introduction

Visually imperceptible image hiding involves hiding one or more secret images into another non-critical image with minimal perceptible degradation. However, the hiding capacity and the distortion of cover image are a trade-off. This is because more hidden information always results in more visually perceptible degradation on the cover image. Recently, visually imperceptible data hiding schemes have been widely studied and many research reports (Chan & Cheng, 2004; Chang & Wu, 2006; Chang, Wu, & Chen, 2008; Chen, Chang, & Hwang, 1998; Chung, Shen, & Chang, 2001; Du & Hsu, 2003; Hu, 2003, 2006; Lin & Shie, 2004; Wu, Lin, & Chang, 2008) have been proposed in the literature. Among these researches, vector quantization (VQ) technique is usually applied in the procedure of data hiding. In addition, the least-significant-bit (LSB) substitution technique is also commonly utilized in the procedure of data embedding.

Visually imperceptible image hiding can be used for covert communication. In the prior researches, raw images without any compression are directly embedded into cover images. To solve the problem of inefficient hiding capacity, Chen et al. (1998) proposed an idea that secret images should be compressed by VQ and then encrypted before the hiding process, which is called virtual image cryptosystem (Chen et al., 1998). In 2003, Hu (2003) proposed a revised algorithm of virtual image cryptosystem (Hu, 2003). In Hu's scheme, each pixel value of the cover image was split into two parts. The significant one is used for VQ codebook training, and the insignificant one is used for data embedding by the greedy substitution. Consequently, several secret images can be hidden into another cover image by Hu's scheme. Hu's scheme provides greater hiding capacity and lower computational cost than that of Chen et al.'s scheme (Chen et al., 1998). It also provides better image

* Corresponding author. Tel.: +886 5 6315575; fax: +886 5 6330456.
E-mail addresses: scshie@nfu.edu.tw, d9021003@msg.ndhu.edu.tw (S.-C. Shie).

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quality for secret images. Nevertheless, the quality of extracted secret images at the receiver is not good enough. Furthermore, the visual quality of secret images decreases badly when more secret images have to be hidden into the cover image. This is because for Hu's scheme, it is necessary to reduce the codebook size for decreasing the volume of each compressed secret image. In order to improve the efficiency of image information hiding, Lin and Shie (2004) proposed a novel idea to transmit a set of secret images via its corresponding VQ codebook (Lin & Shie, 2004). This scheme focuses both on the hiding capacity of the cover medium and on the quality of extracted secret images at the receiver. To achieve a high-capacity and high-quality secret image transmission scheme, the VQ technique is applied in this scheme to compact the volume of secret images. Moreover, to guarantee the visual quality of extracted secret images at the receiver, the VQ codebook utilized in the encoding procedure is adopted as cover medium. Lin and Shie's scheme provides a new and original approach to transmit a set of secret images via network, especially for limited-bandwidth communication channel. Although the appearance of cover medium in Lin and Shie's scheme looks like a meaningless data stream to the possible interceptors, however, the cover medium is a VQ codebook, not a visually recognizable image. This may limit its practical application when the property of visually imperceptibility is required.

In this article, a novel visually imperceptible image hiding scheme that improves both Hu's scheme and Lin and Shie's scheme is presented. To design a high-capacity and high-quality image information hiding scheme, we incorporate the VQ technique into this scheme to compact the volume of secret images. Moreover, to adaptively guarantee the visual quality of extracted secret images at the receiver, the VQ codebook utilized in the encoding procedure is slightly modified and totally embedded into the cover image. The proposed scheme provides a visually imperceptible image hiding approach to deliver a set of secret images to the receiver. The rest of this article is organized as follows. The details of the proposed visually imperceptible image hiding scheme are presented in Section 2. Section 3 addresses experimental results and discussions. Finally, conclusions are given in Section 4.

2. The proposed scheme

In the proposed visually imperceptible image hiding scheme, the input of the transmitter is a set of secret images and a non-critical cover image, and the output of the transmitter is a stego-image with high visual quality. The goal of this scheme is to deliver a set of images secretly via a meaningful cover image of the same size.

Assume that there are t secret images to be delivered and these images are 8-bit gray level images of $w \times h$ pixels. To compress the secret images with VQ, a codebook should be generated before the encoding procedure. Let the size of VQ codebook be N_c and the codeword be composed of $m \times n$ elements. These N_c codewords of codebook are generated based on the Linde–Buzo–Gray (LBG) algorithm (Linde, Buzo, & Gray, 1980) using the secret images as the training set. After the codebook $\boldsymbol{C}$ is generated, each of these secret images is partitioned into blocks of $m \times n$ pixels. Each image block is then encoded into a binary index of codeword. The term of binary index means the index of codeword is manipulated or processed in binary form. That is, each one of the N_c codewords is represented by a bit-string of length $\log_2 N_c$. The compressed message of all secret images is obtained by merging these binary indices. Therefore, the whole volume l (in the unit of bit) of the compressed information for secret images can be defined by the following equation.

$$l = t \times [w/m] \times [h/n] \times \log_2 N_c \tag{1}$$

To embed multiple images into another cover image with minimal perceptible degradation and preserve good visual quality for secret images, the compressed information of secret images is first embedded into the VQ codebook associated with these images and the modified codebook is then embedded into the cover image. Let the number of modified least-significant-bits (LSBs) for each codeword element and each cover image pixel be d and r, respectively. For 8-bit gray level images, the following two formulas must be satisfied to accomplish the proposed image information hiding scheme.

$$l \leqq d \times N_c \times m \times n \tag{2}$$

$$8 \times N_c \times m \times n \leqq r \times w \times h \tag{3}$$

The flow charts of the proposed scheme are given in Fig. 1. Fig. 1a describes the secret image hiding procedures at transmitter whereas the processes of secret image extraction at receiver are presented in Fig. 1b. The relative parameters used in this scheme, t, w, h, m, n, N_c, d, and r, have to be preserved well for future use at the receiver. These parameters can be also embedded into the cover image. Note that the compressed information, the codeword indices, of secret images can be further compressed on the basis of some famous lossless compression techniques such as arithmetic coding (Witten, Neal, & Cleary, 1987) and search-order coding (Hsieh & Tsai, 1996) algorithms. For more security, the modified codebook is encrypted by the DES cryptosystem (National Technical Information Service, 1997) to make it an encrypted and meaningless message. Furthermore, the encrypted codebook can be also losslessly compressed before it was embedded into the cover image. Finally, a stego-image covering a set of secret images is generated.

The procedure of secret images extraction is quite simple at the receiver. To reconstruct the secret images, the encrypted modified codebook and the relative parameters are directly fetched from the stego-image. The encrypted codebook is first decrypted based on the DES decryption procedure. After the decryption process, the modified codebook $\boldsymbol{C'}$ is directly ob-