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Reversible visual transformation via exploring the correlations within color images[☆,☆☆]

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ABSTRACT

Reversible visual transformation reversibly transforms a secret image to a freely-selected target image and gets a camouflage image similar to the target image, which has been proved to be very useful in such two applications: privacy protection of images and reversible data hiding in encrypted images. Now, a new reversible transformation technique for color images is proposed by exploring and utilizing the correlations among three color channels and inside each color channel. The amount of the accessorial information for recording transformation parameters is largely reduced. Therefore, the visual quality of the created camouflage image is much improved by dividing the secret image and the target image into even smaller blocks for transformation.

1. Introduction

Nowadays, images are frequently stored and transmitted on the Internet. However, some images may contain private or confidential information, which should be protected from leakages. Therefore, many methods have been proposed for the purpose of secure image transmission and secure image storage, among which two common approaches are encryption and data hiding.

Although encryption solves the privacy problem in a certain extent, the messy codes of ciphertext with special form are easy to cause the attention of attackers who plan to breakout the accounts of encryption users. However, data hiding technology embeds message into covers such as image, audio or video, which not only protects the content of secret file, but also hides the communication process itself to avoid the attacker's attention.

Traditional highly secure data hiding methods [1–3] are suitable for embedding a small message into a large cover, e.g., an image. But in the applications of image transmission or storage, the image itself is just the message. Therefore, large capacity data hiding technique is applied to hide images. Although large capacity hiding technique is hard to resist the detection of strong steganalysis [4–6], it will be very useful in the applications of protections of images.

Visual transformation can be viewed as a data hiding method having super large payloads, which embeds one image into another one with the same size. We transform the secret image to the target image, getting the camouflage image similar to the target image. From the camouflage image, the recipient can reconstruct the secret image. Note that, the existed visual transformation schemes [7–9] as well as the presented scheme is for images with lossless formats, among which PNG is the most popular lossless format adopted by many camera equipments such as iPhone and IPad.

Visual transformation technique sprouts from Lai et al.'s work [7]. But by Lai et al.'s method, the target image cannot be selected arbitrarily, which must be similar to the secret image. What is more, the visual quality of camouflage image is relatively poor. Then Lee et al. [8] adopt color transformation [10] to transform a secret image to a freely-selected target image, and greatly improve the visual quality of camouflage image. However, one of the main drawbacks of Lee et al.'s method is that the secret image cannot be losslessly reconstructed due to that the adopted color transformation [10] is not reversible.

To overcome the drawbacks of Lai et al.'s method and Lee et al.'s method, we present a reversible visual transformation (RVT) scheme in [9] to transform a secret image to a freely-selected target image by adopting reversible shift transformation. Before shift transformation, a non-uniform clustering algorithm is utilized to match secret blocks and target blocks, which largely reduces the amount of accessorial information (AAI) for recording indexes of secret blocks. With the method [9], not only is the visual quality of camouflage image improved a lot, but also the secret image can be restored losslessly.

In addition to secure image transmission and storage, the RVT scheme proposed in [9] can be also used in some other applications for privacy protection. For example, there comes a novel framework [11]

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for reversible data hiding in encrypted image (RDH-EI) by replacing encryption with the RVT scheme [9]. Note that RDH-EI is a protocol to protect the privacy of outsourced images in clouds by encryption and enables the cloud server to reversibly embed watermark in the encrypted image. Different from all the previous encryption based frameworks [12–14], in which the cloud server and the clients must agree on how to encrypt or decrypt their data, RVT-based framework enables the cloud server to embed data into the "encrypted image" easily by any reversible data hiding (RDH) methods for plaintext images. Thus a client-free scheme for RDH-EI can be realized, that is, the data embedding process executed by the cloud server is irrelevant with the processes of both encryption and decryption.

Although the method [9] improves the methods [7,8] a lot, it does transformation for channels R, G and B of color images separately without exploring and utilizing the correlations among three color channels and inside each color channel, otherwise RVT scheme can be still improved greatly. In this paper, we firstly present an improved reversible shift transformation via assigning a mean class index for each block according to its mean, and the correlations among these mean class indexes are high. Then we explore the correlations within transformation parameters to compress them. Thus AAI for recovering secret image is largely reduced, by which we improve the visual quality of camouflage image through dividing the secret image and the target image into even smaller blocks and transforming secret blocks to corresponding target blocks. Experimental results show that the presented method outperforms the previous methods [7–9] a lot.

The rest of this paper is organized as follows: Section 2 introduces the related work. The proposed method is elaborated in Section 3. Experimental results are shown in Section 4, and the paper is concluded with a discussion in Section 5.

2. Related arts

In the scheme of visual transformation, we divide secret image and target image into small blocks and transform secret blocks to corresponding target blocks to get a transformed image firstly, and then embed the accessorial information for recovering secret image into transformed image with RDH techniques such as [15–18] to yield ultimate camouflage image. At the receiver side, the receiver firstly restore transformed image from camouflage image after extracting these accessorial information, and then restore secret image from transformed image with the help of extracted accessorial information.

The presented RVT scheme is based on the RVT scheme proposed in [9], which consists of two main parts: reversible shift transformation and blocks matching, and is described as follows.

2.1. Reversible shift transformation

We divide secret image and target image into N non-overlapping blocks with the same size. Let the secret block $\mathbf{P}$ be a set of pixels such that $\mathbf{P} = \{p_1,p_2,...,p_n\}$ with symbol u representing its mean, and the target block $\mathbf{P}' = \{p_1',p_2',...,p_n'\}$ with symbol u' representing its mean. The purpose of visual transformation technique is to make the mean and the standard deviation (SD) of each secret block be similar with those of the corresponding target block, by which the secret image will be masqueraded as the target image visually.

A shift transformation is presented in [9] by shifting each pixel of secret block with the amplitude $(u'-u)$. To keep the transformation reversible, the amplitude $(u'-u)$ is rounded to be the closest integer, namely

$$\Delta u = round(u'-u). \tag{1}$$

Δu is recorded for shifting transformed block back to secret block. To reduce AAI for recording Δu, we quantize it by

$$\Delta u' = \begin{cases} 8 \times round\left(\frac{\Delta u}{8}\right), & \text{if } \Delta u > 0 \\ 8 \times floor\left(\frac{\Delta u}{8}\right) + 4, & \text{if } \Delta u < 0 \end{cases}, \tag{2}$$

where function $floor(x)$ means rounding x to be the nearest integer not larger than it. With the quantized $\Delta u'$, the transformed block $\mathbf{P}'' = \{p_1'',p_2'',...,p_n''\}$ is generated as

$$p_i'' = p_i + \Delta u'. \tag{3}$$

Since $\Delta u'$ is quantified by the step length 8 with Eq. (2), $\Delta u''$ is recorded as the parameter for restoring secret block, where

$$\Delta u'' = |\Delta u'|/4, \tag{4}$$

which is in the range of 0–64. Because the correlations among $\Delta u''$s are weak, it will cost much accessorial information to record $\Delta u''$s.

Obviously $\mathbf{P}''$ will have a similar mean with $\mathbf{P}'$ by the shift transformation Eq. (3). To make $\mathbf{P}''$ be more similar to $\mathbf{P}'$ we further rotate it into one of the four directions {0°,90°,180°,270°}. The optimal rotated direction is the one which makes the minimum root mean square error (RMSE) between the rotated version and the corresponding target block.

2.2. Blocks matching

The transformation Eq. (3) shifts the mean of secret block to the mean of target block, but each secret block should be paired with a proper target block before shift transformation, that is pairing each secret block with a target block having a similar SD. In order to reduce AAI for recording the mapping among secret blocks and target blocks, a non-uniform clustering algorithm is proposed for matching secret blocks and target blocks according to their SDs, which is described as follows.

Firstly, all the SDs of secret blocks (and thus the corresponding blocks) are clustered into K classes (called SD class) by K-means to ensure that the SDs in the ith SD class are smaller than those in the jth SD class when $1 \leqslant i < j \leqslant K$. According to secret SD classes' volumes and the scanning order, we cluster target blocks into K classes and set each target SD class to include the same volume as the corresponding secret SD class. If the ith secret SD class includes n_i blocks, then the first n_1 target blocks with the smallest SDs are clustered into the first SD class and the next n_2 target blocks with the smallest SDs of the rest of target blocks are clustered into the second SD class, and so on, until all target blocks are clustered. Therefore, both secret blocks and target blocks are clustered into K classes according to their SDs.

To pair secret blocks and target blocks, each block is assigned with a compound index. That is we scan blocks in the order and the jth block belonging to the ith SD class is labeled as the i_j $(1 \leqslant i \leqslant K, 1 \leqslant j \leqslant n_i)$. With assigned compound indexes, the one to one map among secret blocks and target blocks is established. The i_jth secret block is transformed to the i_jth target block and then the i_jth target block will be replaced by the corresponding transformed block, by which a transformed image will be generated.

Shift and rotation of secret block will not change its SD, thus SDs of transformed blocks will be the same as those of corresponding secret blocks. At the receiver's side, transformed blocks can be clustered into the same K classes as secret blocks, and assigned compound indexes equaling to those of the target blocks at the same position. Secret compound indexes need to be recorded for recovery, to do that we only need record secret SD class indexes in the scanning order. These SD class indexes can be compressed efficiently due to that the distribution of SDs from the divided small blocks is concentrated.

3. Proposed method

As mentioned before, secret image and target image are divided into small blocks for transformation. With the smaller block size, we can get