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A Scalable Reversible Data Embedding Method with progressive quality degradation functionality ☆

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ABSTRACT

This paper proposes a novel reversible information hiding method aiming to achieve scalable carrier capacity while progressively distorting the image quality. Unlike the conventional methods, the proposed method HAM (Histogram Association Mapping) purposely degrades the perceptual quality of the input image through data embedding. To the best of our knowledge, there is no method that attempts to significantly increase the carrier capacity while introducing (tolerating) intentional perceptual degradation for avoiding unauthorized viewing. HAM eliminates the expensive pre-processing step(s) required by the conventional histogram shifting data embedding approach and improves its carrier capacity. In particular, the host image is divided into non-overlapping blocks and each block is classified into two classes. Each class undergoes different HAM process to embed the external data while distorting quality of the image to the desired level. Experiments were conducted to measure the performances of the proposed method by using standard test images and CalTech 101 dataset. In the best case scenario, an average of ~2.88 bits per pixel is achieved as the effective carrier capacity for the CalTech 101 dataset. The proposed method is also compared with the conventional methods in terms of carrier capacity and scalability in perceptual quality degradation.

1. Introduction

Over the years, information hiding has been pursued in two general directions, namely encryption and external data insertion. These disciplines play important roles in digital content management and protection. Recently, they are gaining more attention due to the vast availability of capturing devices at affordable prices and the ever improving internet facilities to share contents in more convenient ways. Among the multimedia contents, image is arguably the mostly considered one.

From the perspective of content (image) management, encryption converts meaningful information into incomprehensible form that appears completely random [1]. One of the common use of encryption is to secure the transmission via public communication channels (i.e., the Internet) to prevent unauthorized viewing, illegal redistribution, etc. However, output from encryption often resembles noise which makes the other operations (e.g., external data insertion, compression) challenging [1]. Therefore, partial encryption (hereinafter referred to as scrambling) was introduced to conceal the perceptual meaning of the content. For instance, Hu et al. proposed to scramble an image by applying XOR operations to pixels using selected rows (columns, or combination of rows and columns) of pixels as the key [2]. Wong et al. proposed UCPF (Unified Constructive Permutation Function) that shuffles indices of the pixels to achieve image scrambling and introduced noise function to further distort the image [3]. Recently, scalability in quality degradation has gained attention in image scrambling because this property is particularly

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useful in hierarchical access control and multilevel content protection, where different quality degradation is applied depending on the access level granted [4]. To this end, UCPF [3] and its improvement [5] are designed to produce different level of distortion (i.e., scalability in visual image quality degradation) by using a control parameter.

Differs from the purpose of scrambling, external data insertion aims to embed data into an image to serve specific purpose. Data inserted into the digital content can be metadata for describing the content, watermark for claiming ownership during a dispute, authentication information for verification of genuinity of the content, secret information in the case of steganography, etc. A commonly considered method to embed external data into a host image is by considering LSB (Least Significant Bits) of the pixel values due to its simplicity in implementation and relatively high carrier capacity. The most straightforward way is to replace the LSB with external data [6] because this approach has insignificant impact to the appearance of the modified image. Another widely considered approach is to modify the LSB by means of adding or subtracting unity to match the external data. To improve image quality, Luo et al. proposed an enhancement of LSB Matching Revisited method by integrating with an edge-adaptive algorithm [7]. More sophisticated methods such as multiple-based notational data embedding method [8] and bit-plane complexity segmentation [9] are proposed to exploit the texture of the host image.

The output for the aforementioned external data insertion methods are not reversible, i.e., data insertion causes permanent distortion or lost of information in the host image [10]. Reversibility is a crucial requirement for applications such as medical, military, forensic, historical artwork preservation, etc., where any form of distortion is not permissible [11]. For that, Tian et al. proposed a lossless method called DE (Difference Expansion) to embed data using simple integer transform between two neighboring pixels [12]. Similarly, Hong's method realized data insertion using DE, but sizes of the blocks resulting from quadtree decomposition determine the embedding pairs and the amount of information to be inserted [13]. Vleeschouwer et al. proposed to embed data into the image by changing the center of mass in the histogram of a block of pixels [11]. Although these two methods are reversible, their embedding capacities are low. Another reversible data embedding method is histogram shifting where empty bins in the image histogram are generated to embed payload [14–16]. This class of data embedding methods is reversible and simple in implementation. However, the embedding process involves expensive pre-processing (i.e., increasing or decreasing magnitude for pixels of value above or below the selected threshold, respectively) and the embedding capacity is still relatively low. In addition, histogram shifting method also requires additional treatment to prevent the underflow and overflow problems.

All the aforementioned methods are meant for a single purpose only, which is either scrambling or external data insertion. However, both disciplines are needed to serve multiple purposes in some applications and hence they are consolidated (e.g., external data insertion and authentication in [17]). One of the applications of the unification of both discipline can be illustrated by using the doctor and nurse scenario. Here, doctor and nurse have different access level to the encrypted patient document in imagery form. The nurse needs access to the external data (e.g., metadata, patient basic information, etc.) for archiving or contact purposes and she does not have the right to amend or view the encrypted content (e.g., patient medical records, medical images, etc.) because only authorized doctor should be given access to these higher level information. Therefore, lower level information can be embedded as external data while the content remains unknown (i.e., encrypted) for the nurse. On the contrary, the doctor can have full access to both the external data and encrypted content using a higher level or additional access key. In another scenario, both disciplines can be combined for digital right management purposes. For example, a fingerprint is embedded into a video to trace illegal distributor and the processed video is scrambled to prevent unauthorized viewing during transmission [18]. For the same purpose, Zhang et al. and Cancellaro et al. proposed a commutative data insertion method in encrypted image in spatial [19] and wavelet [20] domains, respectively. Bouslimi et al. proposed a joint watermarking and encryption algorithm using substitution technique and AES (Advanced Encryption Standard) [21] for secure sharing and transmission of medical image.

In this work, HAM is proposed as a unified method to embed data in an image while progressively distorting its perceptual quality and achieving scalable carrier capacity. To the best of our knowledge, there is no method that attempts to significantly increase the carrier capacity while introducing (tolerating) intentional perceptual degradation for avoiding unauthorized viewing. In particular, in this work, we investigate to what extend information can be embedded while satisfying the reversibility condition. Instead of aiming to maintain high image quality, the proposed method purposely distorts the host image to hide its perceptual meaning. At the same time, higher carrier capacity can be achieved using the proposed HAM method while eliminating the needs to perform expensive pre-processing as required by the conventional histogram shifting-based method. In addition, overflow and underflow will never happen due to the proposed HAM method. The proposed method is applicable in content management scenario where an inferior officer (e.g., clerk, nurse) can extract the inserted information from the perceptually degraded (i.e., scrambled) image to administer the file (e.g., copy, archive, move, etc.). On the other hand, the superior officer (e.g., managing director, doctor) can have access to both the external information and the original image.

The fundamental part of the proposed method is detailed in Section 2 while Section 3 elaborates the enhancements of the proposed method. Additional information of the proposed methods are discussed in Section 4. Experimental results are presented in Section 5 and Section 6 concludes this paper.

2. Histogram association mapping

This section details the HAM as a data representation scheme to encode information and its flow is shown in Fig. 1. The input image G with K-bit depth is divided into non-overlapping blocks $B_\varepsilon(i,j)$ each with size of $b_{\varepsilon_1} \times b_{\varepsilon_2}$