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An efficient reversible data hiding algorithm using two steganographic images

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ABSTRACT

Reversible data hiding (RDH) algorithms are concerned with concealing data within images such that the original image can be fully recovered upon the extraction of hidden data. A substantial interest has grown recently in RDH algorithms that are based on using dual images in order to increase the embedding capacity. In this paper, we propose a RDH algorithm that is based on this concept. Effectively, embedding and extraction of data in the proposed algorithm is performed in three successive phases. In the first phase, four simple rules are used to embed about one bit in each pixel in the two images. On the other hand, the other two phases employ the concept of prediction for embedding secret data bits but without using any complex predictors. Specifically, these phases use one image as the prediction of the other image. Performance evaluation of the proposed algorithm showed its ability to embed around 1.23 bits per pixel with stego image quality above 48 dB. Moreover, the proposed algorithm is of low computational complexity and requires no communication of overhead information.

1. Introduction

The value of data and the advancement in technology has raised the awareness toward increasing the security of data storage and communication. Encryption, which is basically the transformation of data into a form that is not understood by unintended parties is one of the popular techniques for data protection [1,2]. However, this transformation of data may make it more tempting for attackers to decrypt and reveal the data. Another approach that can be used is steganography or data hiding [3]. In this approach, digital data is embedded or hidden into another media, such digital audio, image or video in a way that is hard for attackers to identify the presence of hidden data.

In the digital imaging domain, several algorithms data hiding have been proposed. Most of these algorithms are capable of hiding the data bits in the pixels values [4–8] or in some transformed representation of the image [9,10]. However, these algorithms are not capable of restoring the original image (the cover image) that was used for data embedding after extraction the data. This is a serious problem when it comes to hiding data in medical images, military maps and artworks where minimal changes in the restored cover images after extraction of the embedded data are not tolerable. Accordingly, a great interest has evolved recently in the development of reversible data hiding (RDH) algorithms which are capable of preserving the cover image once the embedded data is extracted. However, the reversibility feature of these algorithms affected the embedding capacity as well as the quality of the image (the stego image) after the data is hidden when compared to non-RDH algorithms. Thus, most of the conducted research in RDH algorithms focuses on improving these two features while guaranteeing reversibility.

Generally, RDH algorithms in the spatial domain can be classified into two groups; difference expansion and histogram-based algorithms. In difference expansion algorithms, the difference between the pixel value and its prediction is expanded and the data bits are embedded in the difference value. Tian [11] proposed the first difference expansion algorithm in which he conducted a two-fold expansion to embed the data. Tian's work was the basis for other algorithms in this category. For example, Alattar extended the basic algorithm to use the difference of four pixels and embedded 3 bits in a 2-fold difference value [12].

Considering the histogram-based algorithms, they are based on analyzing the histogram of the pixels or the prediction error values and then embed the message bits into the most frequent value(s). Ni et al. proposed the first histogram shifting algorithm [13]. The algorithm computes the histogram of the pixels values and then searches for the most occurring (the peak bin) and the least

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occurring value (zero or minimum) bin. Afterward, the histogram bins between the peak and zero bins are shifted toward the zero bin in order to empty the bin next to the peak bin. Data bits are embedded by either keeping the pixels that correspond to the peak unchanged when the bit to embed is 0 or adjusting them to take the value that corresponds to the neighboring bin when the bit is 1. This algorithm showed impressive results in terms of the quality of the stego image as it guaranteed a lower bound on the peak signal-to-noise ratio (PSNR) of 48.1 dB. However, the embedding capacity in Ni's algorithm is dependent on the count of the pixels in the peak bin, which is relatively low in natural images. Nonetheless, the simplicity and the efficiency of the Ni's algorithm triggered the development of several algorithms that are based on the idea of histogram shifting [14,15]. These extensions on the histogram shifting technique showed significant improvement in terms of embedding capacity. Hong et al. [16] extended the basic histogram shifting algorithm by considering the histogram of prediction errors instead of the intensity histogram. The algorithm relied on the fact that prediction errors are sharply centered near the origin, thus higher embedding capacity is expected. Actually, Hong's algorithm showed impressive increase in the embedding capacity when compared to [13] and at the same time it achieved the same lower bound on the image quality since pixels are altered by 1 in the worst case. The idea on using prediction errors was later adopted in many algorithms where the primary difference was in using different or multiple predictors in order to improve the prediction accuracy which is directly proportional to the embedding capacity [17–21].

Although these RDH algorithms were capable of increasing the embedding capacity to rates that may exceed 1 bit per pixel (bpp), this was at the expense of lowering the PSNR value of the stego images significantly. For example, the average maximum embedding capacity for the algorithm proposed in [22] was around 1.58 bpp; however, the average PSNR value was around 32 dB. This might be considered a critical issue for the imperceptibility requirement in data hiding. Accordingly, a new trend in the development of RDH algorithms which considers the use of two or dual images for data hiding has evolved to address this issue. Basically, these algorithms duplicate the cover image and embed the data by manipulating the pixels in the two image copies simultaneously in a way that exploits the similarity between the two image copies in order to increase the embedding capacity while maintaining reasonable high PSNR values for the stego images. As a matter of fact this cannot be achieved in single-image RDH algorithms when they are applied to two copies of the cover image since these algorithms will not take advantage of the similarity between the two covers. Additionally, dual-image RDH algorithms can be claimed to increase the protection of the embedded data [23] since distributing the embedded data across the two images makes it harder for attackers to extract and/or recover the image in case they have one of the stego images.

Chang et al. [23] proposed a dual-image RDH algorithm that uses the exploiting modification direction (EMD) and the modulo function to build a modulo matrix with values in the range 0–255. The data bits are first converted to quinary data and every two pixels in the two images formed a set for embedding. The right and left diagonals of the modulo matrix are then used to create camouflage pixel values. The algorithm achieved an embedding capacity of 1 bpp with PSNR value around 45 dB. The algorithm was further extended in [24] to improve the quality of the two stego images to about 48.1 dB. In [25] a dual-image RDH algorithm was proposed in which one pixel is only modified by ± 1 at most which resulted in improving to the quality to 52 dB but at the expense of reducing the capacity to 0.75 bpp. The quinary representation of data bits was replaced in [26] with a decimal representation. This increased the embedding capacity to about 1.55 bpp; however, the image quality to decreased to around 39 dB.

In [27], Qin et al. performed embedding in the first copy of the cover image based on the EMD concept and modified the second image copy using a set of three rules that are determined adaptively based on the embedding result of the first copy. The algorithm achieved an embedding capacity that slightly above 1 bpp. However, the quality of the two stego images was asymmetric. Lu et al. [28] explored modifying the embedding rules of the least significant bit matching method for reversible data embedding in dual images. Their algorithm was capable of achieving a maximum embedding capacity around 1 bpp with relatively acceptable symmetric image quality around 49 dB. Lee et al. proposed a reversible data hiding scheme based on combinations of pixel orientations in the two steganographic images to enhance embedding capacity and preserve good visual quality [29]. An average embedding capacity of 1.07 bpp was achieved with stego image quality around 49.6 dB. The varying performance of these different algorithms in terms of the embedding capacity, complexity and the quality of the two stego images still has room for further improvement.

In this paper, we propose a novel and simple RDH algorithm that is based on using dual images. Unlike similar dual image RDH algorithms, the proposed algorithm, is not based on the modulo matrix and uses simple embedding rules in order to improve the embedding capacity and reduce complexity. Effectively, the algorithm consists of three embedding phases. The first phase considers modifying the two image copies simultaneously to embed one bit in each pixel in the two images. Afterwards, each of the two subsequent phases considers embedding data in one of the images based on prediction. However, no complex predictors are used in these phases. Alternatively, in each of these two phases, one image is used as the prediction of the other image. The experimental results proved the ability of the proposed algorithm in achieving embedding capacity around 1.23 bpp with image quality above 48 dB for both stego images. On top of this, the processing time requirements of the proposed algorithm are significantly lower than other dual-image RDH algorithms.

The rest of this paper is organized as follows. Section 2 discusses the proposed algorithm. Section 3 presents the experimental evaluation of the proposed algorithm and compares its performance with the state-of-the-art algorithms. Finally, Section 4 concludes the paper.

2. The proposed algorithm

Fig. 1 shows the general framework for the proposed algorithm which consists of three phases. The embedding in the first phase relies on using four simple rules to embed secret bits in the two images simultaneously to produce two temporary stego images. The other two phases rely on the concept of prediction, but without using complex predictors. Specifically, each of these two phases uses one of the temporary stego images that are produced by the first phase as the prediction for the other one. In the following, we detail the operation of these three phases during the embedding and extraction procedures and present simple analysis on the theoretical maximum embedding capacity and the quality of the produced stego images.

2.1. The embedding procedure

The embedding procedure starts by invoking the first phase in which the original cover image is first duplicated to produce two copies of the cover image; namely, CI_1 and CI_2. Afterwards, and in order to provide further protection, the data to be embedded is