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A square lattice oriented reversible information hiding scheme with reversibility and adaptivity for dual images ☆

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ABSTRACT

This paper proposes an adaptive dual-image-based reversible information hiding scheme. First, for a pixel pair in the original image, an associated square lattice is selected to determine the maximum distortion that will be induced by hiding information. Then, an embedding rule, which combines the selected square lattice with integer rounding, is constructed. In addition, a novel histogram shifting mechanism to solve the problems of overflow and underflow is designed to decrease the distortions that are caused by the shifting of a large number of pixels. In our approach, both the original image and the secret messages can be recovered losslessly. Our experimental results show that the proposed scheme achieved performance that was superior to the state-of-the-art schemes, resulting in embedding rates up to 1.40 bpp and average *PSNRs* of approximately 47.60 dB. The proposed scheme also can be used in real-time systems due to the simplicity of its computations.

1. Introduction

The Internet is used extensively throughout the world. The acquisition and sharing of information have become so easy and fast that we ignore the importance of the security of the information most of the time. However, we often highlight information security events that occur from time to time, e.g., when information is illegally monitored, forged, stolen, or disclosed. Cryptography-based information security schemes [1,2], in which information is encrypted and sent to a reliable receiver, are most commonly used to protect private information. This approach ensures that an authorized third party can decrypt the information in a correct manner, but unauthorized parties cannot obtain any meaningful information. Although these schemes work, it is easy for them to attract the attention of unauthorized people. Hence, people in academia have paid more attention to information hiding as a technique for making private information secure and imperceptible to unauthorized people. This technique is used extensively for the secure transmission of multimedia, including digital videos, digital animation, digital text, and digital images. Commonly, the private information is concealed in a stego-image, making it imperceptible to unauthorized people. These stego-images are sent to appropriate people through a transparent channel. However, there are major challenges associated with this technique that must be dealt with, i.e., how to effectively minimize distortions after hiding the information and how to maximize the embedding capacity.

Many information hiding schemes have been researched and published in recent decades. Generally speaking, research related to information hiding can be classified into two categories, i.e., irreversible [3,4] and reversible [5–30,32] information hiding schemes. Irreversible information hiding schemes are designed to work based on concealing confidential messages by modifying the contents of the image, which makes it impossible to completely reconstruct the original image. The advantage of these schemes is that they can achieve high hiding capacity, but, in doing so, the quality of the image is affected adversely.

Reversible information hiding is one technique that has been designed to recover the original image losslessly after the removal of the confidential messages. Compared with irreversible information hiding, the focal points of reversible information hiding are its reversible property and the quality of the stego-image, even at the expense of the partial amount of the hidden message. Hence, researchers have focused mainly on enhancing the hiding capacity and maintaining the original characteristics of the image after it is

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restored. The existing reversible information hiding schemes are classified essentially into four strategies, i.e., lossless compression techniques [5,6], difference expansion techniques [7–11], prediction error expansion techniques [12–15], and histogram shifting techniques [16–20]. The schemes that are based on lossless compression, such as Run-Length Encoding, Arithmetic Coding, and Huffman Coding, usually perform the information hiding process using the space that is vacated when lossless compression techniques are used. The embedding capacity is affected significantly by the performance of the compression method.

In 2002, the first reversible watermarking based on difference expansion was developed by Tian [7,8]. The next year, Tian presented a novel reversible information hiding scheme using difference expansion [9]. In his scheme, the differences in the values of pixels that are positioned adjacent to each other are calculated, and some available values of these pixels are chosen for the difference expansion and are used to embed messages. Inspired by Tian's scheme, an improved generalized difference expansion was proposed by Alattar in 2004 [10]. Alattar extended the difference expansion into the vector that is formed from k non-overlapping pixel values, in accordance with the order determined by a predefined key. His scheme provides a high embedding capacity with low distortion of the image since more available difference values can be generated. In 2008, Kim et al. [11] observed that there was room for improvement in simplifying the location map in Tian's [9] and Alattar's [10] schemes. At the same time, a novel expandability scheme was proposed to achieve more embedding capacity while maintaining the original quality of the image.

Reversible information hiding based on prediction error expansion has been proposed to enhance the payloads. In 2004, Thodi and Rodriguez [12] used a predictor to produce the prediction error values, and they chose them to expand the prediction error values and used them to embed messages. In 2009, Tseng and Hsieh [13] performed some experiments using prediction error expansion. In their scheme, the prediction errors are calculated by using various predictors, including side match, horizontal and vertical predictor, causal-weighted average, and causal-spatial varying filter. Their schemes provide a great embedding capacity without creating additional distortion. In 2013, Qu et al. [14] proposed a new prediction error based reversible information hiding scheme, in which the pairwise prediction error expansion is designed and considered to complete the information hiding. Their scheme achieves a low distortion because it better utilizes the correlation among prediction errors. In 2018, under the frame of pairwise prediction error expansion, Qu et al. [15] presented two new techniques to improve Qu et al.'s scheme [14]. They attempted to build a sharper, two-dimensional histogram and more effective two-dimensional mapping by using adaptive pixel pairing and adaptive mapping selection.

The histogram shifting-based reversible information hiding scheme embeds the message into pixel value or prediction error, whichever has the higher frequency in its histogram distributions. In 2006, Ni et al. [16] used the zero or minimum point of the histogram and embedded the message into the pixel value, which required only a slight modification. In 2009, Tai et al. [17] used a binary tree structure to solve the requirement of prior knowledge of peak and zero points in the decoding phase. Also, they utilized the histogram shifting technique to resist overflow and underflow. In 2013, Li et al. [18] completed information hiding by using a specifically-designed, difference-pair-mapping technique. Later, Li et al. [19] and Wang et al. [20] proposed a model of the modification of multiple histograms based on prediction error expansion to adapt to the requirement of a relatively large payload.

In recent decades, dual-image-based reversible information hiding schemes have been proposed due to the motivation of sharing secrets. These techniques embed the secret messages into two similar stego-images that are copied and generated from the cover image. Thus, the secret messages only can be extracted correctly when the decoder has those two stego-images. Also, the original cover image can be restored losslessly. Hence, dual-image-based information hiding can contribute to the enhancement of the security of secret messages. In 2007, Chang et al. [21] proposed a new information hiding scheme, in which two base-5 secret digits are embedded individually into two stego-images by using a specifically-designed magic matrix. Their scheme can achieve a considerable embedding rate of about 1.0 bit per pixel (bpp), and it provides good quality of stego-images that have an average *PSNR* value of 45 dB. Some non-embeddable pixel pairs exist, which makes the embedding rate in their scheme be less than $(\log_2 5)/2$ bpp. In 2009, Lee et al. [22] presented a novel, dual-image-based, reversible information hiding scheme. Since one pixel pair as the central point has four directions around it, two 2-bit secret messages can be carried by encoding this pixel pair into the corresponding pixel pairs of two stego-images, respectively. Regretfully, to make sure the cover image can be recovered reversibly, the process of embedding in the second stego-image is not always possible or effective. Therefore, its payload is affected adversely by the encoding results of the first stego-image. Their scheme can achieve a high *PSNR* (up to 52.30 dB), but it has a poor embedding rate of about 0.75 bpp. In 2013, inspired by the schemes in [21] and [22], Lee and Huang [23] used the orientation combinations and the enhanced base-5 numeral system to increase the embedding capacity and decrease the distortion of stego-images. The *PSNR* in their scheme can be as high as 49.60 dB, and the embedding rate is about 1.07 bpp. In 2015, Lu et al. [24] employed a center folding strategy to reduce the value of the secret symbols, and then concealed the folded secret symbols in two stego-images through an average method to enhance the image quality. Their scheme is recoverable and achieves an average *PSNR* of 51.40 dB when the embedding rate is around 1.0 bpp. In 2016, Jafar et al. [25] proposed a new reversible information hiding scheme based on the concept of dual images that consists of three successive phases. The first phase embeds one bit in each pixel in two temporary stego-images by modifying pixel values via four rules. Afterwards, each of the two subsequent phases employs the concept of prediction for embedding secret bits. Their scheme is able to embed around 1.23 bpp with the stego-image quality above 48.0 dB. In 2017, Yao et al. [26] presented an improved dual-image-based reversible information hiding scheme on Lu et al.'s scheme [24] by using the selection strategy of shiftable pixels' coordinates with minimum distortion. The average *PSNR* value for the embedding rate of 1.0 bpp is 51.54 dB. Subsequently, Yao et al. [27] further proposed a novel code-mapping based dual-image reversible information hiding method in which the allowably maximum position number is used as the parameter to make a trade-off between capacity and distortion. In 2018, with the guidance of turtle shell-based information hiding, Liu and Chang [28] proposed a dual-image-based information hiding scheme. The variable bits of the secret messages can be shared by two stego-images according to the different mapping location around the diagonal of the reference matrix. The mapping mechanism is that a pixel pair is formed from one pixel and is localized in this reference matrix. Some category rules are used to eliminate the location collision problem. Their scheme has an embedding rate of about 1.0 bpp on average, and the average *PSNRs* of each stego-image are 51.70 dB and 45.70 dB. However, it has the weakness of complex computations, and this results in more execution time. In 2019, inspired by Liu and Chang's scheme [28], Lin et al. [29] proposed a new dual-image-based reversible information hiding scheme. They improved the design of the turtle shell-based