JOURNAL OF INFORMATION SECURITY AND APPLICATIONS 32 (2017) 59–74

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/jisa

Enhancing embedding capacity and stego image quality by employing multi predictors

A.H.M. Kamal *,[1], Mohammad M. Islam [1]

Department of Computer Science and Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

ARTICLE INFO

Article history:
Available online 28 September 2016

Keywords:
Multi-predictor
Prediction error
Hybrid error
Optimal error
Reversible embedding scheme
Embedding capacity and error histogram

ABSTRACT

Prediction error based reversible schemes, which are of a category of single layer data embedment process, conceal message bits mostly into two distinct embeddable errors, e.g. 0 and –1. In the single layer data embedment schemes, the embeddable errors conceive message bit of '0' and '1' through shifting their values by zero and one unit respectively, while the non-embeddable errors must change their values by one just to assist a process of performing reversibility. Hence, the resulting distortions in the stego image overwhelmingly increase along with the rises in the quantity of non-embeddable errors. Increasing the quantity of embeddable errors, thus, enhances both the embedding space and the stego image quality. The authors in this paper enhance the process of increasing the number of embeddable errors –1 and 0 through employing multi predictors, say n predictors, rather than a single one. The prediction errors of these n predictors are measured first. These n prediction errors, relating to each cover pixel, are further employed into m new linear relations to generate m additional hybrid errors. Each optimal prediction error is then extracted from these $n+m$ errors in a manner so that these can be tracked back by the decoder during the de-embedment of the data bits. Simulation results confirm that the proposed scheme provides almost 10%–9233% higher embedding capacity depending on the texture contents of the cover image, while the image quality is improved compared with the competing ones.

1. Introduction

Since the last decade, the applications of covertly transmitting multimedia content have increased rapidly and massively. In many applications, the hiding of secret information in a cover media, more specifically in a cover image, is mostly performed by using either watermarking or steganography. The watermarking techniques are applied mainly into images and documents. In an image, this is used in both invisible and visible modes to protect the ownership and to declare the copyright respectively (Weng et al., 2013). The main objective of applying this technique is to maintain the integrity of the data, i.e., the cover medium, rather than securing the concealed information. The steganography, on the contrary, implants the secret bits into a media, say an image, so that concealed information are hid from all the sensing capabilities of the intruders (Provos, Honeyman, 2003, Brindha and Vennila, 2011; Chien-Chang and Tsai, 2011; Kamal, 2013; Kamal and Mahfuzul Islam, 2014). The image containing the hidden data is then termed as the 'stego image'.

* Corresponding author. Department of CSE, Jatiya Kabi Kazi Nazrul Islam University, Trishal, Mymensingh P.C. 2220, Bangladesh.
E-mail address: kamal@jkkniu.edu.bd (A.H.M. Kamal).
[1] Member, IEEE.

http://dx.doi.org/10.1016/j.jisa.2016.08.005

The steganographic methodologies can be classified into irreversible and reversible processes based on their ability in reconstructing the cover image from the stego one at their data extraction phase. The irreversible techniques focus on extracting the implanted secrets only from the stego image (Böhme and Kirchner, 2013; Chao et al., 2009; Hong and Chen, 2012; Hong et al., 2012; Lee and Chen, 2010; Lee et al., 2014; Lin, 2011; Liu and Liao, 2008; Luo et al., 2011; Ulutas et al., 2011; Wang et al., 2011; Yang et al., 2010), whereas the reversible schemes retrieve both the embedded data and the cover image from the stego one (Chung et al., 2012; Fridrich et al., 2002; Gujjunoori and Amberker, 2013; Hong and Chen, 2010; Kamstra and Heijmans, 2005; Lu et al., 2009; Ong et al., 2014; Tai et al., 2009; Wang et al., 2013, Nguyen et al., 2015). The irreversible schemes are inapplicable when both the extracted information and the cover contents are equally important at the data extractor end for further processing. To manage the reversibility, the reversible schemes implant additional information during their data embedment process. Implantation of these additional bits decreases the original message embedding capacity, known as the pure embedding capacity, and increases some degrees of processing complexity. Nevertheless, these further increase both the security of the message and the robustness of the algorithm as one cannot retrieve and comprehend the secret information without realizing the meaning of these additional bits.

In the reversible data hiding arena, message bits are embedded either by shifting the histogram of the contents in the embedding space, e.g., spatial values, pixel differences and prediction errors, or by expanding the contents in the embedding space. Among these processes, the schemes which utilize prediction errors present both the higher embedding capacity and the better stego image quality because the sharper Laplacian-like distribution of the prediction errors in the prediction error histogram (PEH) allows more errors in the error domain to accept message bits rather than pixels in the spatial domain or the error residues in the difference domain. These also cause the pixels to be shifted by fewer amounts because the frequency of unaltered pixels increases along with the increment of embeddable pixels. Moreover, these schemes provide stronger security of the embedded data because of their undisclosed parameters like applied predictor, starting point of predictions in the image, number of associated pixels in the predictor and the other parameters of the predictor's own.

In the prediction error based reversible data embedment processes, a predictor first predicts either a single pixel (Hong, 2012) or a block of pixels (Hong and Chen, 2010) by exploiting the features of spatial association among the neighboring pixels of the cover image. Predictors are therefore classified as either 'single pixel predictor' or 'block pixel predictor'. Associated pixels, used to predict the target ones by the predictor, remain unchanged during the data hider process, also termed as the encoding process, for the benefits of extracting secret messages at the receiver. In both cases, subtracting the predicted values from their corresponding cover pixel values generates the prediction errors. Bit implantation process embeds data bits into two or more highest frequency errors. The single layer data embedment processes conceal data bits mainly into two highest appeared errors (Ou et al., 2013; Yang et al., 2013). The other errors are shifted by one unit to give space for the movement required for data concealment into these two embeddable errors. The multi-layers embedding schemes (Hong, 2012; Kamal and Islam, 2016b), on the other hand, implant data bits into more than two highest appeared errors. These increase the embedding capacity, but destroy the stego image quality notably. The applications, which are sensitive to stego image quality, thus prefer to embed data bits into single layer. The research presented in this paper aims to enhance both the embedding capacity and the stego image quality.

As a 'single pixel prediction' (SPP) scheme, Ou et al. (2013) proposed a scheme that predicts a pixel, say x, by using a partial differential equation (PDE). Four gradient differences, measured from x and each of its four neighbors on top, right, bottom and left, are employed in the PDE to approximate a value of x. Let x^1 be the primary estimation for x. The estimation process repeats for t times, $t > 0$, for better predicting the value of x. At each prediction step t, the process calculates four gradients of x^t, executes the PDE with new gradients to estimate the next step predicted value, x^{t+1} and updates x^t with x^{t+1} until the PDE goes to a stable state. A parameter, known as the 'stable parameter', controls the number of iterations. A static 'stable parameter' cannot predict all the pixel values, which are close to accurate. Dynamic valued 'stable parameter', on the contrary, reduces the pure embedding capacity, as the parameter information also needs to be implanted for the reason of assisting the decoding process at the receiver end. The scheme proposed by Yang et al. (2013) predicts values from a weighted average of its four neighbor pixels on the left, right, top and bottom. During the estimation of a pixel, the weights for vertical and horizontal neighbors are assigned by analyzing its vertical and horizontal gradient responses. For each pixel, the scheme applies Sobel and interpolation masks of size 5×5 in measuring these two gradient responses along its vertical and horizontal directions. Based on these responses, the scheme then allots more emphasis on either the vertical or the horizontal pixels by assigning more weights to them. The scheme, however, ignores the diagonal gradient responses and, thus, estimates poorly in many instances. Ma et al. (2015) presented a different scheme where they had employed multiple predictors so that an optimal one could be selected from the multiple predicted values. The scheme first predicts a pixel by each of the predictors separately and then measures the optimal predicted values verifying three situations — optimal value is a one of the predicted values if all the predictions are of the same worth; the minimum of the n-predicted values is an optimal one if the cover pixel is less than that minimum value; and finally, the maximum of the predicted values is an optimal one if the cover pixel is greater than that maximum value. The scheme avoids the cover pixels, whose values are within the range between the minimum and maximum predicted values, although such pixels are large in quantity. To reduce the distortions in the stego image, Chen et al. (2013) employed two asymmetric predictors; separately one for embedding bits at the right direction and another for embedding bits at the left direction into a single most appeared prediction error of the error histogram. The scheme only presents a new mechanism of embedding bits for twice rather than improving or proposing a new predictor. The scheme proposed by Wang et al. (2013) classifies the pixels into two groups: wall pixel (i.e., border pixels) and non-wall pixels. Interpolation errors are