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Original

A novel Diamond-Mean predictor for reversible watermarking of images☆

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Abstract

Reversible watermarking (RW) is the art of embedding secret information in the host image such that after extraction of hidden information, original image is also restored from the watermarked image. Prediction error expansion (PEE) is state of the art technique for RW. Performance of PEE methods depends on the predictor's ability to accurately estimate image pixels. In this paper, a novel Diamond-Mean (D-Mean) prediction mechanism is presented. The D-Mean predictor uses only D-4 neighbors of a pixel, i.e. pixels located at {east, west, north, south}. In the estimation process, apart from edge presence, its orientation and sensitivity is also taken into account. In experimental evaluations, the D-Mean predictor outperforms currently in use MED (median edge detector) and GAP (gradient adjusted predictor) predictors. For, standard test images of Lena, Airplane, Barbara and Baboon, an average improvement of 51.79 for mean squared PE and an average improvement of 0.4 for error-entropy than MED/GAP are observed. Payload vs imperceptibility comparison of the method shows promising results.

Keywords: Prediction; Error-expansion; Reversible watermarking; MED; GAP; D-Mean

1. Introduction

Internet is a highly convenient medium for transmitting and sharing of multimedia data. It rejuvenated businesses by attracting large number of customers. With the ease of access and increased business benefits, arises a greater challenge of ownership and authenticity of the media content. Watermarking of multimedia content is a very popular technique of coupling secret information with images and videos.

Image watermarking is the art of hiding 'secret message' in the image in such a way that it should not cause any visible distortion. It is one of the recent image protection methods, which provides security against illegal production and re-sharing of the copyright content. The process of hiding secret information is called as 'watermark embedding'. When an image, also known as 'cover-image', undergoes embedding process it is called as 'watermarked-image'. The main objective of watermarking is to make the watermarked-image alterations imperceptible to the image viewer, i.e. the quality of cover-image and watermarked-image should be visually identical. The amount of data that can be successfully embedded and retrieved in the cover-image is called as 'payload' of the embedding method. Increase in payload affects the imperceptibility negatively and vice versa.

Methods that can extract the watermark (hidden message) as well as completely retrieve the cover image from its watermarked-image are called as reversible watermarking (RW) methods (Caldelli, Filippini, & Becarelli, 2010). Recovery of the cover image is very important in medical imaging or in military applications where even a minute alteration/distortion is unacceptable. An MRI or CT scan image of a patient if not fully recovered might endanger the life of a patient by misleading the physician. Other applications of RW include remote sensing (Barni, Bartolini, Cappellini, Magli, & Olmo, 2001) and multimedia archive management (Park, 2014). Many reversible watermarking techniques has been proposed in the most recent literature (Kotvicha, Sanguansat, & Kasemsa, 2012; Shi & Xiao, 2013; Song, Li, Zhao, Hu, & Tu, 2015; Zhang, Qian, Feng, & Ren, 2014; Zhao & Feng, 2016).

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Tian (2003) introduced difference expansion transform for RW which was followed by prediction-error expansion (PEE) method by Thodi and Rodríguez (2004, 2007) they introduced histogram-shifting (HS) which significantly reduced location map (LM) size. Since then, many variations of PEE based methods (Kamstra & Heijmans, 2005; Luo, Chen, Chen, Zeng, & Xiong, 2010; Peng, Li, & Yang, 2012; Sachnev, Kim, Nam, Suresh, & Shi, 2009; Tai, Yeh, & Chang, 2009; Wang, Li, & Yang, 2010) were developed. Performance of these methods heavily rely on the predictor's ability to accurately predict image pixels. In most of the methods researchers investigated different embedding mechanisms while not much work is being done in developing new predictors. MED (Weinberger, Seroussi, & Sapiro, 2000) and GAP (Wu & Memon, 1997) are mostly used predictors by these methods.

In this paper a novel predictor for reversible watermarking is proposed. The predictor accurately models the flat and edge regions in an image hence better prediction of pixels which leads to less distortion of watermarked image. Improved embedding of watermark in conjunction with histogram shifting and D-Mean predictor led to gain higher imperceptibility levels for a given payload.

The paper organization is as follows: In the next section relevant reversible image hiding methods are discussed. In Section 3, MED and GAP are reviewed and novel D-Mean predictor is presented. Reversible watermarking method based on the proposed predictor is discussed in Section 4. Experimental setup and results are provided in Section 5 and conclusions are drawn in Section 6.

2. Related work

First expansion based method was presented by Tian (2003) and it achieved moderate payload with good image quality. In this method, image is divided into pairs of pixels and each pair based on its mean and difference value undergoes 1 bit of data embedding. Let (x_0, x_1) be the values of a pair of pixels, then integer mean and difference are denoted as $l = \lfloor (x_0 + x_1)/2 \rfloor$ and $h = x_1 - x_0$. To embed 1 bit watermark $b \in \{0, 1\}$ in h, it is expanded to $h' = 2h + b$ and watermarked values (x'_0, x'_1) are obtained using Eq. (1). For an easy reference, notations used in the paper are summarized in Table 1:

$$x'_0 = l - \lfloor h'/2 \rfloor \\ x'_1 = l + \lfloor (h' + 1)/2 \rfloor \quad (1)$$

Pairs which are not suitable for data embedding are listed in location map (LM). For successful extraction of hidden data and restoration of cover image pixels, LM is also stored in the watermarked-image alongside embedded bits as overhead information. Originally, image pixel values range from 0 to 255 for an 8 bits per pixel representation. Expanded pixels which lie outside the permissible range are marked as unexpandable pairs in LM. Size of LM hampers the embedding capacity (EC); therefore reduction in its size is very important, hence researchers are using lossless compression methods to reduce its size. Using Tian method, 1 bit can be embedded in each pair of pixels while 1 bit for each pair is also required in LM hence space for data embedding is created by lossless compression of LM.

Table 1
Notations.

Symbol	Description
h	Difference of pixels
h'	Expanded difference after embedding of data
e	Prediction error
E	Expanded prediction error
x	Original pixel
$\hat{x}$	Estimate/prediction of a pixel
x'	Watermarked pixel
T	Embedding capacity threshold
T_S	Edge sensitivity threshold used in D-Mean predictor
S_{PE}	Entropy measured over PE of a predictor
I	Original Image
Θ_1 and Θ_2	Two disjoint sets of an image
Ψ	Pixels which can be modified twice without producing overflow
Φ	Pixels which can be modified once and will lead to overflow upon 2nd modification
Υ	Pixels which cannot be modified
b_h	hard bit used for testing of overflow
$\mathcal{D}_u$	Watermark data to be embedded in the image
$\mathcal{D}$	Payload which includes auxiliary information, LM and watermark data
A_i	Auxiliary information necessary for watermark extraction
T_v	Pixel selection threshold based on variance of the context
$v(\cdot)$	Variance of a set of pixels
N_{LM}	Length of location map
$\odot$	Concatenation operator

Alattar (2004) extended the idea of a pair to k pixels cell. Each cell has been used to hide $k-1$ bits. For each cell one bit is required in LM, this helps decrease the size of LM to $(1/k)$th the image size. Unexpandable cells cannot be used for embedding due to problems of underflow or overflow (noted as overflow), so payload of the method is always less than $(k-1)/k$ bpp (bits per pixel).

Location map is the bottleneck of reversible image hiding methods. Even compressed LM takes significant part of the payload. Thus, LM size determines the performance of a method. Later, authors investigated methods that generate small-size location map or no map at all. Lee, Yoo, and Kalker (2007) used block-based approach with integer-to-integer wavelet transform to hide data. An image of size $X \times Y$ is divided into blocks of size $N \times M$. The method produces relatively small LM and better exploits redundancy present in the sub-bands of wavelet transformed coefficients, hence, outperforms Tian (2003) and Alattar (2004).

Image pixels are highly correlated with neighboring pixels. Thodi and Rodríguez (2004) used MED predictor to predict image pixels from their neighborhood pixels. The prediction error (PE) is used to hide watermark bits instead of difference between pairs of pixels. In prediction, more than one pixel of the neighborhood is used which results in smaller PE. PE denoted as e of a pixel x having prediction value $\hat{x}$, is computed using Eq. (2). In Thodi and Rodríguez (2007), HS was incorporated in