Int. J. Electron. Commun. (AEÜ) 70 (2016) 211–224

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

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

PEE based RW using fuzzy conditional entropy for image partitioning

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ARTICLE INFO

Article history:
Received 8 May 2015
Accepted 13 November 2015

Keywords:
Prediction error expansion
Reversible watermarking
Conditional entropy
Attacks

ABSTRACT

Prediction error expansion (PEE) based reversible watermarking (RW) has found to be efficient for meeting the high embedding rate at low visual distortion. However, the existing works mostly use single predictor over the entire host image. Further performance improvement is possible using predictors based on local characteristics of the image. To this aim, this work first proposes a method to partition the image into different regions, namely the smooth, the texture and the edge regions using multiple thresholds on pixel gradients. The threshold values are calculated by maximizing the fuzzy conditional entropy of the gradient values. The optimal set of parameters for the fuzzy membership functions are specified by differential evolution method. Two predictors are then proposed, one for prediction of gray values in the edge region and the other one for the texture and the smooth region. RW is then done using region specific PEE. A large set of simulation results are shown to highlight its improved rate-distortion performance over the existing works followed by semi-fragile nature of watermark decoding against common operations like smoothing filtering, noise addition, cropping, random bending attack, etc.

1. Introduction

Reversible watermarking (RW) embeds some useful information on image, audio or video data followed by lossless watermark decoding that leads to reconstruction of the host data in a reversible manner [1–3]. This reversibility is very much important in various fields, specially for medical and military applications. Hence, RW becomes an important research field over the last decade. Literature on RW is rich with different algorithms, namely lossless coding [4–7], histogram bin shifting [8–13], difference expansion [14–22], reversible contrast mapping (RCM) [23–27], prediction error expansion (PEE), etc. [9,19,22,28–43]. Among them, PEE based RW scheme is the most promising one in term of its improved embedding rate-distortion trade-off performance. PEE is one form of modification on the previously proposed difference expansion based RW algorithm [14]. According to difference expansion algorithm, the secret bit and the auxiliary information are embedded on the least significant bits (LSBs) of the difference in intensity values for the chosen pixel pair when no overflow or underflow appears. It is observed in difference expansion based algorithm that lower is the difference value, higher is the embedding rate.

Thodi and Rodriguez [31] first proposed the use of simple PEE algorithm using median edge detector (MED) predictor for RW. According to this algorithm, the difference between the pixel and its predicted value (i.e. prediction error) is expanded for data embedding. MED is a simple yet high performance predictor already used in JPEG-LS standard. Besides MED, some other popular predictors are gradient adjusted predictor (GAP), simplified GAP (SGAP), history based blending predictor, simple and fast lossless compression algorithm (SFALIC) predictor, differential adaptive run coding (DARC) predictor, gradient edge detection (GED) predictor, minimum mean square error predictor, least absolute deviation (LAD) predictor, etc. and their usages are reported in the literature for PEE-RW algorithms [9,28,31,44,45].

A simple RW method based on PEE was reported by Tseng et al. [33], where only two pixels were used for prediction purpose. Later on Sachnev et al. [46] reported rhombus pattern based prediction algorithm where the prediction errors are sorted based on magnitude of its local variance. Dragoi et al. [29] reported an extended version of [46] by performing adaptive prediction of the pixel values that do not belong to smooth regions. Coltuc et al. [30] presented a PEE based high capacity multi-bit embedding algorithm. Wu et al. [47] proposed a histogram shifting based hybrid approach for watermark embedding. Zhou et al. [48] reported an optimization technique for capacity enhancement. The full context based prediction is reported by Chen et al. [49] to get better prediction accuracy. Tudoroiu et al. [50] reported a block map based

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http://dx.doi.org/10.1016/j.aeue.2015.11.010
1434-8411/

RW using MED predictor. The compensation technique based PEE-RW algorithm is reported by Luo et al. [51]. The compensation process improves spatial correlation in the neighbourhood pixels and results in better prediction accuracy. Coltuc [36] reported an improved embedding for the PEE based RW by reducing the embedding distortion on the cover image. The proposed method divides the expanded error between the current pixel and its predefined neighbourhood. Coltuc [28] proposed a novel RW algorithm based on PEE where prediction of pixel value was made using the current pixel of its three neighbouring pixels. This work claims that prediction error is much lower than other high performance predictors such as MED and GAP. Li et al. [52] reported a PEE-RW scheme where high imperceptibility in term of peak-signal-to-noise-ratio (PSNR) is achieved based on block based pixel value ordering. The dynamic prediction error based on histogram shifting is used by Coatrieux et al. [53] for watermark embedding.

PEE based RW algorithms offer the improved performance on capacity-distortion trade-off (obtained so far among the reported RW algorithms [9,19,22,28–43]). However, a single predictor is mostly used over the entire image without exploiting the predictor's adaptive nature on the characteristics and content of the host image. On the contrary, the existing works also report that the different parts of an image offer different performance gain during watermark embedding. Hence, an image adaptive prediction is an important issue for performance improvement in RW. An image is partitioned in different regions, namely the smooth, the texture and the edge regions. However, it is not always possible to crisply assign an individual pixel to a distinct type/class, as a pixel value, based on its neighbourhood characteristics, also show some degree of belongingness to other region. Hence optimal partitioning of an image into different distinct regions is an important research issue. Several algorithms for image partitioning/segmentation are reported including fuzzy set theoretic approaches [54–57], gradient based partitioning [58], etc. In [56], a three level thresholding on gray values based on the maximum fuzzy entropy was used for image segmentation. A set of parameters describe the fuzzy functions and the optimal values for this set that maximize fuzzy entropy is determined by genetic algorithms (GA). In [57], the authors extend the work of [56] for matched filter response on retinal images using DE-based fuzzy conditional entropy maximization for extraction of different types of blood vessels. Two points of the work on [56] need further discussion. First one is the fuzzy entropy maximisation for finding the threshold values; entropy calculation over the whole regions of the smooth, the texture and the edge are computationally expensive. Furthermore, thresholding is done on this gray-values which are integers and GA is found to be efficient for parameter search.

To reduce the computation burden, instead of entropy, fuzzy conditional entropy is used in [57] to find threshold values. Moreover, instead of gray values, edge gradients are used here for thresholding. This shows more efficient image partitioning/segmentation over fuzzy entropy maximization of [56]. Since gradients are real numbers, differential evolution (DE) instead of GA, can be used for finding the parameter values of fuzzy functions. In general, DE offers better system stability over GA; hence an average improvement in image partitioning is expected to be achieved.

This paper proposes an algorithm for PEE based RW where the prediction used are adaptive to image characteristics. First the host image is partitioned into the smooth, the texture and the edge regions using fuzzy conditional entropy maximization on image gradient. DE is used for parameter specifications of the fuzzy functions. Two predictors are then proposed, one (Predictor 1) using the 3-neighbours (left, left diagonal and vertical) of the pixel value to be predicted and other one (Predictor 2) using the horizontal and the vertical gradients involving six neighbours in 8-connectivity. Predictor 1 is used on the edge regions, while the predictor 2 is used on the smooth and the texture regions. Data embedding is then done based on PEE. A large set of simulation results are shown to highlight the improved performance on rate-distortion and robustness against smoothing filtering and noise addition. The latter set of performance results support the semi-fragile nature of the proposed RW method. Performance comparison with respect to the existing PEE works and other image partitioning methods [58] are also reported.

The rest of the paper is as follows: Section 2 describes fuzzy conditional entropy based image partitioning using DE. Two predictors are then proposed in Section 3. Proposed PEE-RW is described in Section 4 and its performance results are reported in Section 5. Finally concluding remarks and scope of the future works are made in Section 6.

2. Gradient based image partitioning using fuzzy conditional entropy and DE

This section first proposes an image partitioning technique. Pixel value gradients are used for image segmentation/partitioning as well as for image quality assessment [58]. In [58], a fixed scale factor on the maximum gradient magnitudes are set to partition images into the edge, the texture and the smooth regions, the three distinguishable regions through which any natural image is characterised. SSIM value on each region is pooled to obtain 3-SSIM value as global quality assessment indicator. This partitioning is based on hard thresholding where individual region is assumed to be well separated from the other regions. However, a particular pixel value possesses different membership with respect to different regions i.e. a partial overlapping on different regions is expected to exist for range of gray values. Different membership functions on pixel gradient may be used. The optimized threshold values are calculated using DE through the maximization of fuzzy conditional entropy applied on the pixel gray value gradients. The block diagram of the proposed algorithm is shown in Fig. 1.

2.1. Calculation of pixel value gradient

Different image regions are found to be sensitive on the embedding process in different ways in term of data embedding rate and visual distortion. This demands the use of proper predictors so that

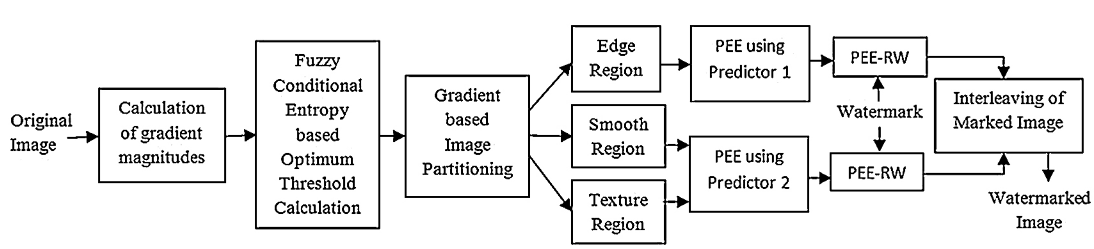

Fig. 1. Proposed watermark embedding scheme.