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Region based interpolation error expansion algorithm for reversible image watermarking

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A B S T R A C T

In this paper, we propose a new reversible image watermarking method based on interpolation-error expansion called region based interpolation error expansion (RBIEE). We improved Thodi's prediction error expansion (PEE) technique by using a novel interpolation algorithm which exploits interpixel correlation better. Furthermore, interpolation error histogram is divided into two regions. The parameters of each region are determined separately and iteratively to reach a given embedding capacity more precisely. However, adaptive embedding strategy is utilized to get better capacity-distortion performance. Advantage of the proposed method over the other state-of-the-art methods in terms of capacity and visual quality is demonstrated experimentally.

1. Introduction

Digital watermarking is expressed as a data hiding technique which is developed for purposes such as identification, copyright protection and indexing of digital media content. In this technique, a secret data called watermark is embedded into the digital multimedia content. In the decoder, watermark data is extracted from the watermarked signal in a lossless manner although original signal cannot be obtained back. However, in some important applications such as military imaginary, forensic law and medical imaginary, distortion in the original signal may cause fatal results. For instance, a small distortion in a medical image may interfere with the accuracy of physician diagnosis. Distortion problems which may arise in applications above mentioned can be fixed in a reversible watermarking method [2]. In a reversible watermarking technique, original signal is represented in a new domain to create an empty space. That empty space is exploited for watermark insertion. Then, both watermark data and original signal can be reconstructed in a reversible manner by going back to the original representation.

Reversible image watermarking (RIW) algorithms can be classified into five groups. Lossless compression based algorithms [5,7,3,4], difference expansion (DE) based algorithms [16,1,8,12,13], histogram shifting (HS) based algorithms [14,6,11,17,9], prediction-error expansion (PEE) based algorithms [10,15] and integer to integer transform based algorithms [18]. Recent studies have been focused on the PEE based algorithms which give effective results in terms of capacity-distortion performance. PEE combines difference expansion and histogram shifting methods. It exploits spatial correlation more efficiently than DE by watermarking prediction error instead of pixel difference. PEE takes advantage of HS approach to make room for data embedding. Several PEE based methods have been presented in the literature. Each of these methods obtains prediction error in a different way to exploit spatial correlation between neighboring pixels more efficiently. In almost all PEE based RIW methods; prediction error histogram of the image is calculated first and then the histogram is divided into two distinct region according to the capacity parameter (t) which is determined depending on the size of the watermark data. Fig. 1 shows the divided regions and prediction error histogram. Pixels in inner region are expanded by adding 1 bit watermark data while pixels in outer region are shifted [15]. In order to achieve a given target capacity, capacity parameter is increased iteratively.

Performance of a reversible image watermarking (RIW) method is measured by embedding capacity, visual quality and complexity. Due to advances in computer technology, complexity could be ignored. Capacity and visual quality are inversely proportional. Increasing embedding capacity leads to image quality deterioration. Although, there are very effective algorithms in the literature, PEE based RIW algorithms can still be improved. Embedding

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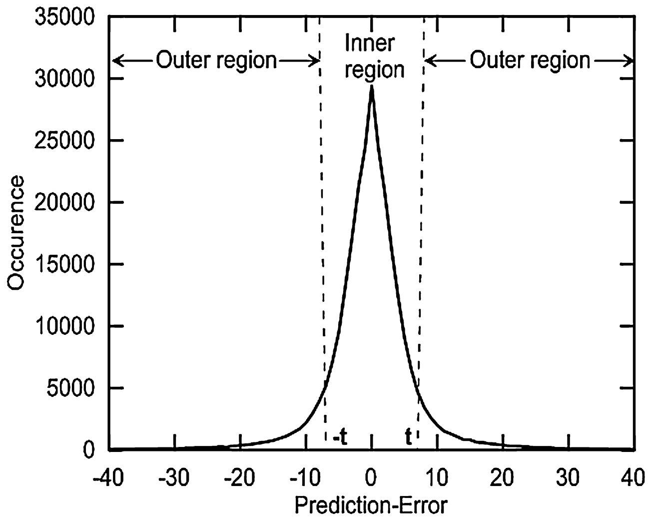

Fig. 1. Prediction error histogram of lena.

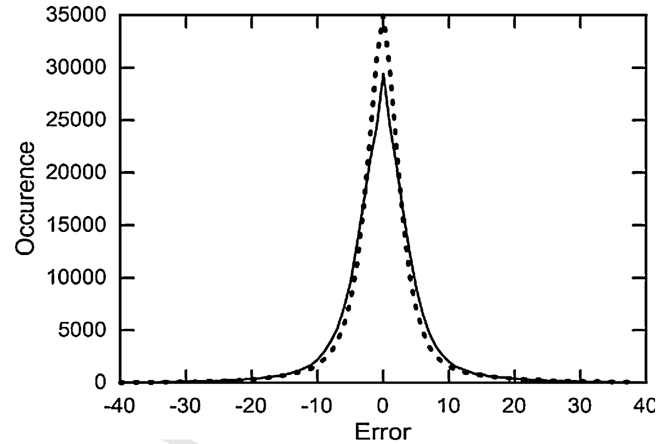

Fig. 2. Dotted line is interpolation error histogram and line is prediction error histogram of lena.

capacity can be increased by using more correlated pixels while visual quality is preserved by different watermarking approaches.

In this study, we propose a novel RIW method which has a better capacity-distortion performance. The proposed method embeds data into the interpolation-error which exploits the correlation between adjacent pixels more efficiently than prediction error. In order to watermark the interpolation error histogram, a new reversible watermarking method called region based interpolation error expansion (RBIEE) has been developed. RBIEE is a kind of PEE method which divides the interpolation error histogram into two sub-regions and capacity parameters of both regions are calculated separately. However, each sub-region is watermarked according to its own capacity parameter. Thus, desired embedding capacity is reached more accurately. Therefore, visual quality can be controlled more precisely than in conventional PEE based algorithms. Furthermore proposed algorithm exploits correlation between adjacent pixels by interpolation method. Since interpolation error is smaller than prediction error, interpolation error histogram becomes sharper. Therefore, proposed method gives better capacity-distortion performance. Adaptive embedding strategy proposed by Li et al. [10] is exploited in our method by applying it to the interpolation-errors to get high embedding capacity. Also, pixel selection algorithm is utilized to improve visual quality.

We improved the Li et al.'s method by using more than one capacity parameter to control visual quality more precisely for a given payload. When Li et al.'s method is applied to our method, some problems can be encountered such as obtaining same interpolation error in both sides, distributing payload homogeneously to the image pixels especially at low capacities, embedding and obtaining the side information reversibly. However, for each problem, we proposed an original solution in our watermarking algorithm. Efficiency of our method over state-of-the-art methods in terms of capacity and visual quality has been demonstrated according to the experimental results.

The rest of the paper is organized as follows. Image interpolation, region based interpolation-error expansion, pixel classification, adaptive watermarking and pixel selection are explained in Section 2. Additional information, embedding and extraction algorithms are explained in Section 3. In Section 4, our method is evaluated in comparison with conventional reversible watermarking algorithms. Finally, conclusions are drawn in the last section.

2. Region based interpolation error expansion

In this paper, instead of conventional reversible watermarking scheme described above, we present a new reversible watermarking method that utilizes more than one maximum point of interpolation-error histogram to embed data. Capacity and image quality of our method are enhanced by an adaptive approach and pixel selection method. Especially, pixels in smooth regions of image are used for watermarking to decrease the number of watermarked pixel count. In this section, image interpolation, region based interpolation error expansion, pixel classification, adaptive embedding and pixel selection algorithms have been explained respectively.

2.1. Interpolation

Our data hiding scheme utilizes the interpolation algorithm presented by Zhang et al. [19]. Using interpolation-error in a data hiding scheme has two important advantages compared with other methods [19]. The first one is that almost all the pixel values are used for data embedding. For instance, in Tian's method, interpixel difference is expanded. Hence, the number of difference values is only a half of the total number of pixels which means that potential embedding capacity of the scheme is cut in half. The second one is that the correlation between neighboring pixels is exploited more efficiently in interpolation methods. Therefore, the peak point of interpolation-error histogram becomes higher than prediction-error histogram. This can be seen in Fig. 2. As a result of that, capacity of watermarking increases. Proposed interpolation algorithm applied both in embedding and extraction phases is capable of estimating the same interpolated image for both processes.

Fig. 3 illustrates the pixels of a 5 × 5 image in which the cover image is divided into two sets denoted as "sampled" and "non-sampled". The pixels denoted with letter indices are called sampled pixels and the others are called non-sampled pixels. The interpolation of non-sampled pixels P_{22}, P_{24}, P_{42}, P_{44} are calculated from nearest sampled pixels. For instance, interpolated value of P_{22} is obtained by using $P_{\{a,b,d,e\}}$ pixels. Let the mean value of sampled pixels (P_a, P_e) and (P_b, P_d) be denoted by Mp_{ae} and Mp_{bd}, respectively. Interpolation-error $e_{ae}$and e_{bd} are obtained via

$$e_{ae} = MP_{ae} - P_{22}$$

$$e_{bd} = MP_{bd} - P_{22}$$

Mean value of the sampled pixels is $k = \sum_{x=\{a,b,d,e\}}(P_x/4)$. For a given non-sampled pixel, weight of neighbor non-sampled pixels

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