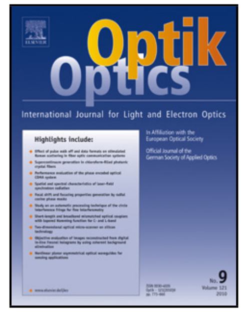
Accepted Manuscript



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PII: S0030-4026(17)30900-2
DOI: http://dx.doi.org/10.1016/j.ijleo.2017.08.008
Reference: IJLEO 59471

To appear in:

Received date: 4-2-2017
Revised date: 31-7-2017
Accepted date: 1-8-2017

Improved reversible data hiding using pixel-based pixel value grouping

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***Abstract*—Pixel value grouping (PVG) has been proved effective in exploiting block redundancy. However, the uniform pixel block still exposes the deficiency in generating prediction errors in a block-by-block manner. In this paper, a novel pixel-based pixel value grouping (PPVG) is proposed with which the embedding primitive switches from pixel block to pixel and PVG is fulfilled on context pixels to calculate predicted value. In this way, not only the advantage of PVG can be preserved but also all pixels can be fully utilized and classified. Then more and smaller expandable prediction errors can be obtained by utilizing pixels in smooth regions with priority. As a result, the embedding procedure can embed more data with less distortion. Experimental results verify that the proposed scheme outperforms other state-of-the-art schemes.**

***Index Terms*—Reversible data hiding, pixel-based pixel value grouping, pixel value grouping, pixel selection**

Keywords: Reversible data hiding; pixel-based pixel value grouping; pixel value grouping; pixel selection

1. INTRODUCTION

Data hiding [1] enables one to embed secret message into the host media for the purposes of copyright protection, authentication, etc. Due to the ability to recover the host media exactly as well as extracting the embedded data [2], reversible data hiding (RDH) has become one of the most important branches of data hiding and has been applied to many quality sensitive fields such as medical imaging, remote sensing and military. So far, many RDH schemes have been proposed and they can be mainly classified into three categories, i.e., lossless compression based, difference expansion based and histogram modification based.

Early schemes are mostly based on lossless compression technique [3-5]. In 2003, Tian [6] firstly proposed the idea of difference expansion (DE), where secret message is embedded by expanding the difference between adjacent pixels. Although the embedding capacity (EC) is bounded by 0.5 bpp (bits per pixel), DE provides larger EC with less distortion when compared with lossless compression and thus has been widely investigated and developed [7-11]. In 2007, Thodi [10] proposed an effective extension of DE called prediction error expansion (PEE), where the target pixel is predicted by neighboring pixels and then the prediction error is utilized for expansion embedding. Compared with the simple pixel difference used in DE, much smaller prediction errors which guarantee lower distortion can be obtained by complex predictors [12-16]. Moreover, PEE can also be developed by location map reduction [17], context modification [18], adaptive embedding [19-20], two-dimensional histogram modification [21-22] and pixel value ordering [23-27].

In 2006, Ni [28] proposed another remarkable work of RDH based on histogram modification. In this scheme, the peak point of intensity histogram is utilized for data embedding while those between the peak point and zero point are simply shifted by one unit. As a result, high marked image quality and low computational complexity are guaranteed. As the sharpness of the histogram is significant to embedding performance, Lee [29] and Tsai [30] sequentially proposed to utilize difference histogram and prediction error histogram. Afterwards, multilevel histogram modification [31-34] and multilayer embedding [35] were proposed to achieve sufficient EC. Li [36] presented the general framework to histogram modification based RDH.

Histogram modification based schemes can be divided into two categories: single level histogram modification based [20-27] and multilevel histogram modification (MHM) based [31-34]. The main feature of single level histogram modification is that the maximum modification is always 1 and hence high visual quality is guaranteed at the cost of limited EC. Among existing schemes, the idea of pixel value ordering firstly proposed by Li [22] is commonly treated as the most effective prediction method. On the other hand, MHM offers a direct way to achieve larger EC and the number of histogram bins utilized for data embedding indicates the embedding level (EL). The larger EL is, the larger EC and severer distortion is. In this case, the construction of histogram becomes the key to scheme performance.

In MHM-based RDH, the difference/prediction error histogram can be generally constructed in pixel-by-pixel manner [31-32] or in block-by-block manner [33-35]. In [31], a pixel sequence consisted of all pixels is obtained via the inverse “S” order scan and then the differences of adjacent pixels are computed and employed for difference histogram construction. Fu [32] improved the differences concentricity around zero by involving more adjacent pixels in predicted value computation. The high redundancy