Comment on "Watermarking With Flexible Self-Recovery Quality Based on Compressive Sensing and Compositive Reconstruction"

Paweł Korus and Andrzej Dziech

***Abstract*—This is a supplementary document to the manuscript "An Efficient Method for Content Reconstruction with Self-Embedding", submitted to IEEE Transactions on Image Processing. It describes the necessary modification to the self-embedding scheme [1], which needed to be introduced to guarantee its proper operation for dark and bright images.**

I. Introduction

This paper addresses a reference value quantization problem in the scheme from [1]. Due to insufficient range of the quantization code-book, the reference values are excessively saturated. The problem occurs for images with dark and bright regions, and results in disturbing reconstruction artifacts. Depending on the amount of such content, the restored fragments might be either distorted or completely indiscernible.

The problem can be solved by using a more coarse code-book with a greater range of reference values. Such enhancement limits the achievable reconstruction fidelity, but allows for correct operation, regardless of the image content. We compare the performance of the modified scheme with the original one in a common evaluation scenario.

II. Problem Description

In this section, we briefly introduce the operation of the addressed scheme, with emphasis on the problematic quantization procedure. We use the notation from the original publication.

The operation of the algorithm begins with a division of the input image into 8×8 px blocks. The blocks are then divided into $N/1024$ groups, 16 random image blocks each. Within each such group, the discrete cosine transform (DCT) coefficients are collected in a zig-zag order to form a single 1024-element vector $\mathbf{v}$.

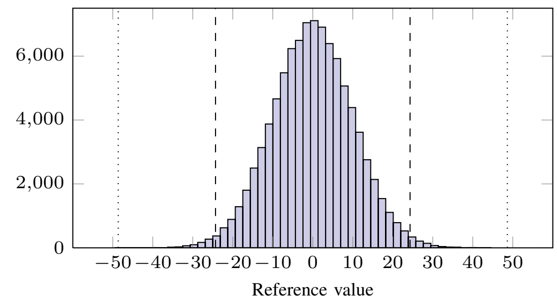
A pseudo-random Gaussian matrix A is then used for projection of $\mathbf{v}$ onto a 368-element vector of reference values:

$$\begin{bmatrix} r(1) \\ r(2) \\ \dots \\ r(368) \end{bmatrix} = \mathbf{A}\mathbf{v}.$$

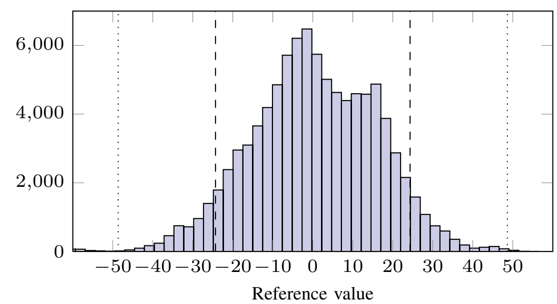
The elements of $\mathbf{A}$ are selected from an i.i.d. Gaussian distribution with zero mean. The matrix is normalized so that each row would have its Euclidean norm equal to 1. The reference values approximately meet the Gaussian distribution.

The obtained reference values are then randomly permuted, and divided into $N/64$ sets of 23 values. Each such set is then embedded into a single image block. For the purpose of watermark generation, the values are quantized in a nonuniform manner, with better precision for small magnitudes. The originally used quantizer assumed that the typical range of reference values is approx. $[-24; 24]$. However, for practical implementation of the scheme, the range is not sufficient.

The DCT is computed on individual image blocks, after discarding 3 least significant bit-planes, and subtracting a constant value 16, which corresponds to the medium block intensity. In case of images with near-average brightness levels, the DC coefficients are small, and the reference values are usually in the originally expected range.



(a) 9011.png, overexposed fragments



(b) 1341.png, night photography

Fig. 1: Histograms of reference values for two example images. The original and the modified ranges are marked with dashed and dotted lines, respectively.

For blocks with average intensity close to 0 or 31, the DC coefficients will be large, and will result in greater reference values with a disturbed distribution. Such situation corresponds to dark and bright blocks. Two example histograms of the reference values are shown in Fig. 1.

The resulting saturation of the reference values causes restoration artifacts. The more bright or dark blocks in the image, the more severe artifacts are to be expected. Two reconstruction examples are shown in Fig. 2, which illustrate various extents of the problem. In case of the night photograph, the original reconstruction result is completely indiscernible. In case of the slightly overexposed image in Fig. 2ab, the originally restored areas are affected by the artifacts, although it is still possible to recognize the content.

Based on the statistics from 10,000 natural images from the BOWS2 data-set [2], the typical range of the reference values is twice the original, i.e., $[-48, 48]$. Hence, the problem can be fixed by using $f'_t = 2f_t$ instead of f_t:

$$f'_t = \frac{t}{3} + \frac{t^2}{150}, \qquad t = 0, 1, \dots, 64. \tag{1}$$

The resulting more coarse quantization limits the achievable reconstruction fidelity, but allows for correct operation, regardless of the image content.

III. Experimental Evaluation

We assess the impact of the introduced modification on a set of 48 gray-scale natural images of size 512×512 px, selected from the BOWS2 data-set [2]. The selected images span the space of possible characteristics, i.e., include dark, medium, and bright images with various amount of details, measured as an average standard deviation of individual 8×8 px blocks.

P. Korus and A. Dziech are with the Department of Telecommunications of the AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Kraków, Poland, E-mail: pkorus@agh.edu.pl, dziech@kt.agh.edu.pl

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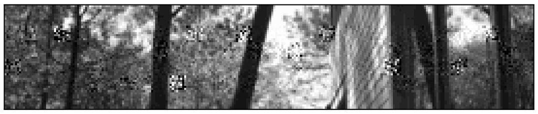
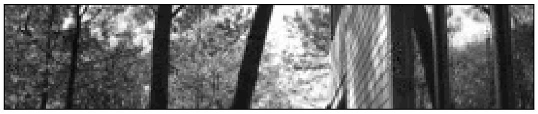
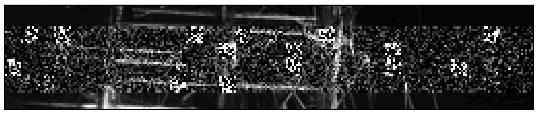


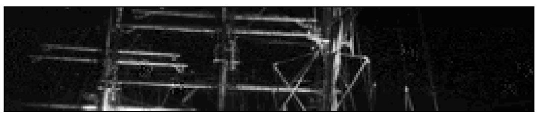
(a) 9011.png, original scheme, 22.0 dB



(b) 9011.png, fixed scheme, 32.7 dB



(c) 1341.png, original scheme, 12.3 dB



(d) 1341.png, fixed scheme, 33.1 dB

Fig. 2: Reconstruction results for the original and the fixed schemes on two example natural images. The tampering is a horizontal stripe through the center of the image; the tampering rate is 12.5%

TABLE I: Reconstruction quality scores

Scheme	**Reconstruction quality for various tampering rates**						
	2.5%	5%	10%	20%	30%	40%	50%
Average PSNR for all images, [dB]							
Original	33.7	33.4	31.5	29.1	27.3	27.0	25.7
Fixed	37.8	37.2	34.8	31.7	29.1	28.1	26.5
Average PSNR for properly restored images only, [dB]							
Original	39.6	39.4	37.9	34.4	31.6	30.4	29.1
Fixed	38.3	37.8	35.6	33.2	31.0	30.3	29.1

The selected images are watermarked with both the original and the fixed encoder, and then randomly modified with the tampering rates from 0.025 to 0.5 with a 0.025 step. The experiment is repeated 30 times, with different seeds for the pseudo-random number generator.

The reconstruction PSNR scores for selected tampering rates are collected in Table I. The reported values are average PSNR scores calculated separately for both the complete test set, and only for the images correctly reconstructed by the original algorithm. The latter set contains images where 99.99% of the reference values are within the $[-24, 24]$ range.

It can be observed, that the introduced modification has improved the average reconstruction quality. The improvement reaches 4 dB. Although the maximal reconstruction fidelity is lower, all of the images are now restored properly. The negative quality impact is usually not disturbing. For individual images, the average PSNR deterioration reaches 2.2 dB. For lower tampering rates, where the achievable quality is nearly maximal, such a difference might not be perceptible. For higher tampering rates, where the restoration is mainly performed by compressive sensing, there are no statistically significant differences in the reconstruction quality.

IV. Conclusions

In conclusion, by using a more coarse quantizer with a wider range of representable reference values, the scheme from [1] can properly restore images with dark and bright content. The resulting lower precision of the reference values has a minor negative impact on the restoration fidelity, which on average does not exceed 2.2 dB.

References

[1] X. Zhang, Z. Qian, Y. Ren, and G. Feng, "Watermarking with flexible self-recovery quality based on compressive sensing and compositive reconstruction," *IEEE Transactions on Information Forensics and Security*, vol. 6, no. 4, pp. 1223–1232, 2011.

[2] "The dataset from the 2nd bows contest," http://bows2.ec-lille.fr/, 2007, Visited on 26 March 2012.