An Approach to the Optimal Watermark Detection

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Abstract— **An approach to optimal watermark detection in the DCT domain, based on the probability density function (pdf) modeling, is presented. A new detector is proposed in order to produce reliable detection of weak watermarks for various distributions of DCT image coefficients. Efficacy of the proposed detector is proved on some common attacks, as well.**

I. Introduction

Intensive digital multimedia communications result in significant requests for an efficient protection of digital data (audio, image and video). Digital watermarking is an approach used to this purpose [1]-[4]. The first task in digital watermarking techniques is in finding an appropriate scheme for inserting an invisible signal (watermark) containing the information about the copyright holder. In many applications the watermark should be robust to various signal processing algorithms (attacks) [4]. The second requirement is that there should exist a reliable procedure for watermark detection [1], [5], [6].

This paper is focused on the second topic. A digital watermark embedded in the DCT image domain is considered for this purpose. In order to meet watermark invisibility requirements, the watermark is embedded in a set of the coefficients, excluding those with the highest magnitude. The new detector is based on an appropriate pdf modeling of the DCT image coefficients. It is reliable for high pseudo signal to noise ratio (PSNR), even for PSNR as high as 60dB. It means that the proposed detector can be useful for medical applications where the sensitive information in images should not be changed by the watermark. The proposed detection scheme is tested on some common attacks: JPEG compression, median filtering, additive impulsive noise combined with median filtering, additive Gaussian noise.

AEUE International Journal of Electronic and Communications, Vol.57, 2003.

II. Watermark Embedding

The watermark embedding in the DCT domain is considered. The embedding algorithm stems from [7]. The DCT coefficients, denoted by I_i, are reordered into a decreasing sequence:

$$I = \{I_i \quad | \quad |I_i| \geq |I_{i-1}| \; i = 1, 2, ..., N\}, \quad (1)$$

where N is the total number of the DCT coefficients. Since the watermark embedding in the coefficients with highest amplitudes could produce image deformation, the first L transformation coefficients are omitted $(i = 1, 2, ..., L)$ and the watermark is embedded in the next K coefficients $(i = L + 1, ..., L + K)$. The watermark is not embedded in the lowest coefficients $(i = K + L + 1, .., N)$, as well, because it could be easily removed by a lossy image compression or by a low pass filtering without perceptual degradation of an image.

The secret watermarking key is created as a set of the Gaussian random numbers with zero mean and unitary variance. Then, the DCT coefficients of the watermarked image can be written as [5], [7]:

$$I_{wi} = I_i + \alpha |I_i| w_i, \quad (2)$$

where α is the parameter controlling the watermark influence and $i = L+1, .., L+K$. Although, it has been shown that the DCT coefficients of an image have a dominant Laplacian pdf [5], [6], [8], for the sequence in (2), the pdf will be significantly changed, since the watermark is embedded in the selected coefficients defined by L and K. The distribution of the DCT coefficients, where the watermark is embedded, determines the optimal detector.

III. Watermark Detectors

The problem of finding the optimal detector can be considered as the detection of a sequence w (known signal) in the watermarked image I_w. Consider the optimal detector in the form [9]:

$$D = \sum_{i=L+1}^{L+K} w_i g_O(I_{wi}), \quad (3)$$

where:

$$g_O(I_w) = -\frac{p'(I_w)}{p(I_w)}, \quad (4)$$

$p(I_w)$ is the pdf of the watermarked coefficients, and $p'(I_w)$ is its derivative. Commonly used watermark detectors assume a Gaussian pdf of the DCT coefficients. The detector function (3),(4) is then linear:

$$D_G = \sum_{i=L+1}^{L+K} w_i I_{wi}. \quad (5)$$

Since the distribution of coefficients (2), in general is not Gaussian, detector (5) is not optimal.

An example with pdf function of coefficients used for watermarking is given in Fig.1 (the image "Lena" is used, with $L = 1500$, $M = 3000$). We can notice that this pdf exhibits significantly different form than the Gaussian distribution.

Note that the presented pdf can be better approximated by a function of the form:

$$p(I_w) \sim \frac{(I_w/a)^{2n}}{1 + (I_w/a)^{2n}} \exp(-(I_w/a)^2), \quad (6)$$

where parameter n controls the decay of $F(I_w) = (I_w/a)^{2n}/(1 + (I_w/a)^{2n})$ between maxima and origin, and a is the position of the pdf maxima. Note that the function $F(I_w) \to 1$ for $|I_w| > |a|$ and $n \gg 1$, meaning that the $p(I_w)$ approaches to Gaussian form in this region. The function (6) fits not only the presented image, but a large variety of images we have considered.

Thus, better results can be achieved by using the detector that corresponds to this pdf than by (5). The optimal detector that results from (6), (4) and (3) is:

$$D_{OPT} = \sum_{i=L+1}^{L+K} w_i \left(I_{wi} - \frac{na^2}{I_{wi}[1 + (I_{wi}/a)^{2n}]} \right). \quad (7)$$

The standard detector follows for $n = 0$. In order to avoid possible zero value of I_{wi} the threshold β will be used. Thus, I_{wi} takes a greater value from the set $\{I_{wi}, \beta\}$.

The proposed watermark detector is tested with large number of trials, where the detection is performed with exact and wrong (arbitrary) keys. As a measure of the detector quality the following ratio is used:

$$R = \frac{\overline{D}_{key} - \overline{D}_{wrong}}{\sqrt{\sigma_{key}^2 + \sigma_{wrong}^2}}, \quad (8)$$

where $\overline{D}$ and σ are the mean values and the standard deviations of the detection values, while notations "key" and "wrong" are used for the true and wrong watermarking keys. Note that the ratio R determines the probability of detection error [7]. The pdf $p(I_w)$ is a function of the parameters L and K, i.e., $p(I_w) = f(L, K)$. Thus, it is important to provide a set of non zero $(L + K)$ coefficients. Larger L and K produce better invisibility, while smaller values result in more robust watermarking.

Example 1: Efficiency of the proposed detector for very high values of the PSNR is considered. We have used watermarked images "Lena", "Baboon", and "Arctic hare", whose size was 256×240 pixels, Fig.2, with $L = 1500$ and $K = 3000$. For each key w, R is calculated by using 100 wrong keys w_{wi} (thus we use in (8) $\sigma_{key}^2 = 0$ and $\overline{D}_{key} = D_{key}$). Tests are performed with 100 different keys which show variation of R by using different keys. The ratio R is shown for all images in Fig.3. The obtained values for the PSNR are between 56 and 59 dB. In this example the parameters $\alpha = 0.03$, $\beta = 1$ and $n = 8$ are used.

Example 2: We have detected watermark in the attacked images, as well. The following parameters are used $L = 300$ and $K = 300$.

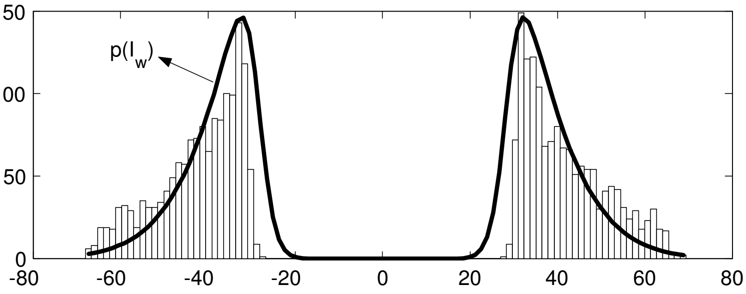

Fig. 1. Histogram of DCT coefficients with approximation $p(I_w)$.

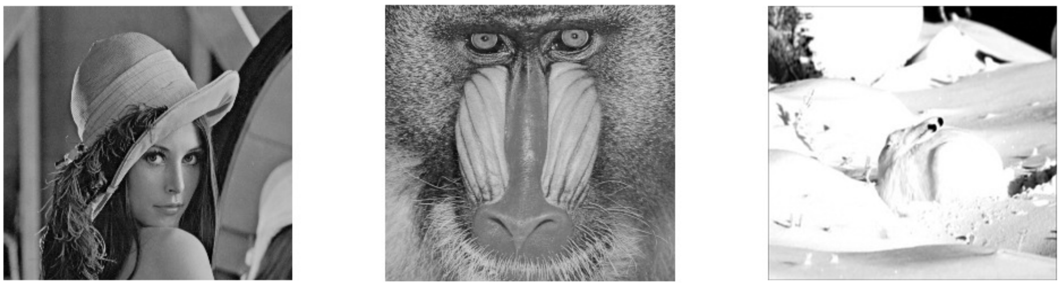

Fig. 2. Test images: (a) Lena; (b) Baboon; (c) Arctic hare.

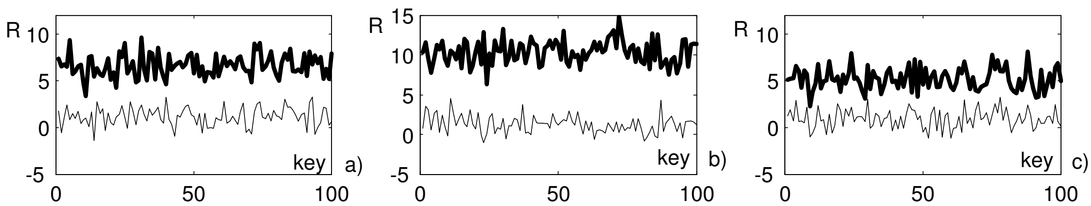

Fig. 3. Ratio R for images from Fig.2 in 100 trials, respectively: Proposed detector - thick line; Linear-standard detector - thin line.

The first row of Fig.4 presents the ratio R for non attacked images. Second, third and fourth rows present this ratio after JPEG compression (with quality of compression 40%), Gaussian noise of variance 0.001, and median filtering (3×3), respectively. Similar results are obtained in the case of combined impulse noise and median filtering attacks. Values of the PSNR were from 46 to 48 dB. The parameter values $\alpha = 0.09$, $\beta = 1$ and $n = 4$ are used.

As shown in the examples this detector significantly outperforms the standard one.

In the previous two examples an optimal analytical determination of the parameters n, L and K is not done. It could be a topic in future work.

IV. Conclusion

It has been shown that the optimal watermark procedure requires appropriate approximation of the pdf function of the watermarked DCT coefficients of image. Based on this analysis, the new form of the pdf function which provides an optimal watermark detector is proposed.

V. Acknowledgment

The work of Srdjan Stanković was supported by the Alexander von Humboldt foundation,

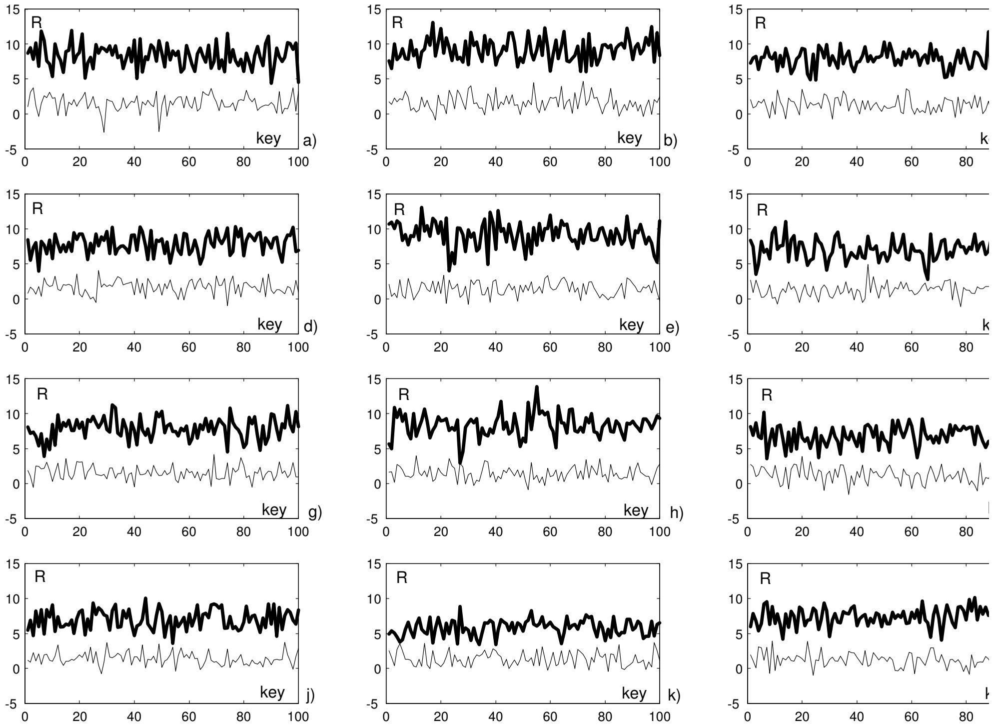

Fig. 4. Watermark detection: non attacked images-First row; Attacked images: JPEG compression- Second row; Additive Gaussian noise- Third row; Median filtering- Fourth row. Columns are from Fig.2, respectively. Thick lines-proposed detector. Thin lines-standard detector.

the work of Igor Djurović was supported in part by the JSPS foundation, the work of LJubiša Stanković is supported by the Volkswagen stiftung, Germany.

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