# EMBEDDING PARAMETRIC DIGITAL SIGNATURES IN IMAGES

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**ABSTRACT**

A new approach to digital image signatures (watermarks) is proposed in this study. An image signature algorithm consists of two stages : signature casting and signature detection. In the first stage, small changes are embedded in the image which afterwards are identified in the second stage. After chosing certain pixel blocks from the image, a constraint is embedded among their Discrete Cosine Transform (DCT) coefficients. Two different embedding rules are proposed. The first one employs a linear type constraint among the selected DCT coefficients and the second assigns circular detection regions, similar to the vector quantization techniques. The resistance of the digital signature to JPEG compression and to filtering are analyzed.

## 1 INTRODUCTION

Image signature algorithms represent a new, fast emerging area in image processing. The image signatures (watermarks) are used to identify the owner of a certain image and thus to avoid the unauthorized distribution of digital image copies [1]. The digital signing algorithms must fulfill certain requirements. Thus, the digital signature must not distort visually the image and should be resistant to different image processing algorithms.

Various algorithms were lately proposed for image copyright protection. They deal with either embedding small changes in the graylevel domain [2] or in DCT domain [3]. The image signature problem can be treated as an application of the signal detection theory [2].

The proposed signature casting algorithms consist of two processing steps. In the first step the positions of certain pixel blocks are selected in the image based on the decision of a Gaussian network classifier. The inputs in the classifier are the distances measured in the number of blocks between each two selected blocks. The graylevels of these blocks are modifyed such that a constraint is embedded in their DCT coefficients. In the first approach we embed a linear constraint and in the second we define circular detection regions around certain selected coefficients. The digital signatures embedded by the proposed algorithms are designed to be resistant at the standard image compression algorithm [4]. The DCT coefficient modification is directly related to the assumed compression ratio. This means that we are able to embed a signature that resists up to a certain compression ratio. The signatures can be identified exclusively from the image context without needing the original image. The modifications brought by the signature are image dependent. The signature can be identified in each frame of a signed image sequence.

## 2 BLOCK SITE SELECTION

In this stage certain pixel blocks are selected in the image according to a parametric based relation. The image is partitioned in blocks of size $8 \times 8$ pixels, similar to the block size considered in the JPEG compression algorithm [4]. The selection of the locations is based on a Gaussian network classifier :

$$\sum_{i=1}^{L} \exp\left[-\sum_{j=1}^{N} \frac{(x_j - w_{i,j})^2}{r_{i,j}^2}\right] > \alpha, \qquad (1)$$

where the inputs $x_j$, for $j = 1, \ldots, N$ are the distances between each two consecutive block locations, $L$ is the number of Gaussian functions and $w_{i,j}$, $r_{i,j}$ are the network parameters provided by the signature code. The output of the network must be larger than a level $\alpha \in (0,1)$ for a selected location. The value $\alpha$ splits the range of all possible distances between two chosen locations, in two classes: those which fulfill the condition imposed by the signature and those which do not fulfill it.

In the signature casting stage, we should use the inverse of the relation (1). Let us consider as known the first $N-1$ distances between each two consecutive chosen sites to be signed, $x_j = d_j$ for $j = 1, \ldots, N-1$. From (1) we obtain the following range of block sites that all fulfill the given relation :

$$w_{i,N} - T_{i,N} < x_N < w_{i,N} + T_{i,N}, \qquad (2)$$

$$T_{i,N} = r_{i,N} \sqrt{\ln\frac{1}{\alpha} - \sum_{j=1}^{N-1} \left(\frac{d_j - w_{i,j}}{r_{i,j}}\right)^2}. \qquad (3)$$

For consecutive block distances, the Gaussian functions are activated in a certain order, only one at the time. The requirement imposed to the coefficients of the Gaussian network to set up such a classifier is to form a circulant matrix :

$$w_{i,j} = w_{(i+1) \bmod L, j-1}, \tag{4}$$

$$r_{i,j} = r_{(i+1) \bmod L, j-1}, \tag{5}$$

for $i = 1, \ldots, L$ and $j > 2, \ldots, N$. Only one block location is chosen from the entire range of possibilities, based on the minimal distortion produced in the image. A given block site can not be situated in the activation range of two different Gaussian functions. In order to avoid this, we set up the following condition :

$$\min \{w_{i,j-1}, w_{i+1,j}\} > T_{i,j} > 1, \tag{6}$$

for $j = 2, \ldots, N$, $i = 1, \ldots, L$ and $T_{i,j}$ is provided in (3).

The bounds of the selected blocks number denoted by $n$ are :

$$\frac{MRL}{64 \sum_{i=1}^{L} (w_{i,N} - T_{i,N})} > n > \frac{MRL}{64 \sum_{i=1}^{L} (w_{i,N} + T_{i,N})}, \tag{7}$$

where $M \times R$ is the image size and $T_{i,N}$ are the distances recursively calculated in (3).

The proposed algorithm for block site selection allows to embed the signature locally, in a certain part of the image. The position of these regions depends on the signature parameters and scanning order. Such a region contains all the image blocks situated between the chosen block sites which activate the first and the last unit ( i.e., the $L$-th ) from the Gaussian network (1). The number of pixels contained in a such of region is situated in the following range :

$$64 \sum_{i=1}^{L} (w_{i,N} - T_{i,N}) < s_k < 64 \sum_{i=1}^{L} (w_{i,N} + T_{i,N}), \tag{8}$$

where $s_k$ is the number of pixels from a signed region, $k = 1, \ldots, \left\lfloor \frac{n}{L} \right\rfloor$.

## 3 DCT COEFFICIENT CONSTRAINT

JPEG is the standard image compression algorithm which consists of three main processing blocks : Discrete Cosine Transform (DCT) block, the quantizer and the entropy coder [4]. After selecting certain block locations based on (3), their pixels are modified such that they fulfill a constraint in the DCT domain. Usually, the energy of the image is concentrated in the low frequency domain (regarding the respective frequency range) and the high frequency components represent only a small ratio of the total energy. The signature embedded in the DCT coefficients should produce unnoticeable distortions in the image. The coefficients corresponding to the high frequency domain are cut off by the JPEG quantizer and they are not suitable to be used for embedding a constraint. On the other hand, modifications in the low frequency range may cause visible alterations in the image. The most suitable DCT frequencies to be used for embedding a constraint are those from the middle range [3] :

$$(u_i, v_i) \in \{(1,1), (1,2), (2,1), (3,1), (2,2), (1,3)\}. \tag{9}$$

The forward DCT transform is applied on the $8 \times 8$ pixel blocks [4] :

$$F_j(u,v) = \frac{1}{4} C(u) C(v) \left[ \sum_{k=0}^{7} \sum_{l=0}^{7} f_j(k,l) \cdot \cos \frac{(2k+1)u\pi}{16} \cos \frac{(2l+1)v\pi}{16} \right], \tag{10}$$

$C(u), C(v) = \frac{1}{\sqrt{2}}$ for $u, v = 0$ and $C(u), C(v) = 1$ otherwise; $f_j(k,l)$ are the image pixel values contained in the $j$-th block, and $F_j(u,v)$ are the transform coefficients.

The first algorithm considers a linear constraint among the selected DCT coefficients :

$$Y = \mathcal{F} \mathbf{Q}, \tag{11}$$

where $\mathcal{F}$ is the vector of the modified DCT frequency coefficients, and $\mathbf{Q}$ is the weighting vector provided by the signature. We employ the least squares algorithm for embedding this constraint.

The second algorithm defines circular regions around the selected DCT frequency coefficients. The coefficients of the selected frequencies have assigned certain values according to :

$$\|\mathcal{F} - \mathbf{Q}_k\|^2 = \min_{i=1}^{H} \|\mathcal{F} - \mathbf{Q}_i\|^2 \text{ then } \mathcal{F} = \mathbf{Q}_k, \tag{12}$$

where $\mathbf{Q}_i$, $i = 1, \ldots, H$ is the set of coefficient vectors provided by the signature. This approach is similar to the DCT vector quantization.

After embedding either the constraint (11) or (12), the image graylevels are reconstructed based on the new DCT coefficients :

$$g_j(k,l) = \frac{1}{4} \left[ \sum_{u=0}^{7} \sum_{v=0}^{7} C(u) C(v) \mathcal{F}_j(u,v) \cdot \cos \frac{(2k+1)u\pi}{16} \cos \frac{(2l+1)v\pi}{16} \right], \tag{13}$$

where $g_j(k,l)$ are the pixel values of the $j$-th block from the signed image.

From all the blocks that fulfill the condition (1), only the block which produces a minimal image distortion according to the mean absolute difference criterion, is chosen :

$$k = \arg \min_{j=b+w_{j,N}-T_{j,N}}^{b+w_{j,N}+T_{j,N}} \sum_{x=0}^{7} \sum_{y=0}^{7} |f_j(x,y) - g_j(x,y)|, \tag{14}$$

where $b$ denotes the position of the last chosen block site according to (1), $T_{j,N}$ is given by (3) and $k$ is the selected block.

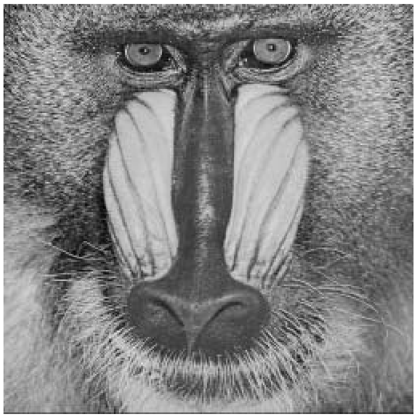

Figure 1: The original "Baboon" image.

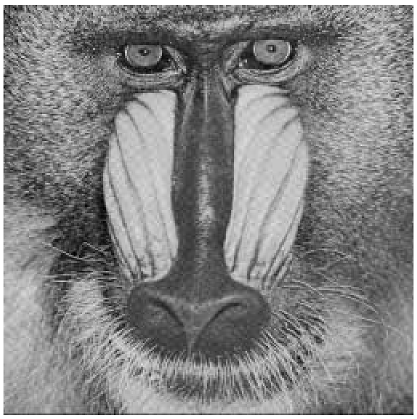

Figure 2: Signed image based on linear DCT constraint.

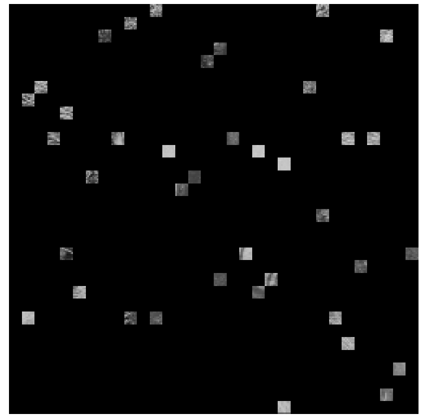

Figure 3: Selected block sites.

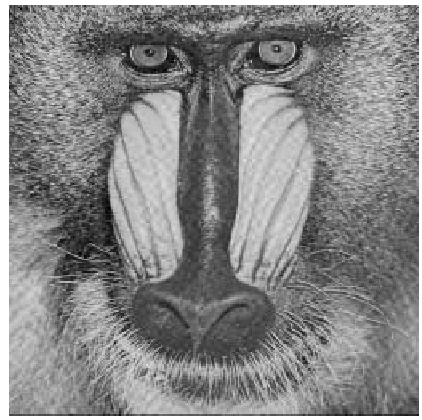

Figure 4: Signed image based on quantization.

## 4 DIGITAL SIGNATURE DETECTION

In the signature detection stage, we evaluate which block sites fulfill the DCT constraint (11) or (12) and afterwards the location constraint (1). The main distortions produced by JPEG compression algorithm are caused by DCT coefficient quantization and rounding [4]. These distortions produce changes in the DCT coefficient values and consequently may affect the embedded relations (11) or (12).

In order to cope properly with JPEG distortions we define detection regions of certain size, in DCT coefficient domain. The DCT constraint relations for the proposed algorithms are :

$$\hat{\mathcal{F}}\mathbf{Q} < D_L, \quad (15)$$

$$||\hat{\mathcal{F}} - \mathbf{Q}_k||^2 < D_C, \quad (16)$$

where $D_L$ and $D_C$ determine the detection region size and correspond to a certain compression ratio and $\hat{\mathcal{F}}$ denotes the DCT coefficient vector in the detection stage. The detection region size parameters, $D_L$ and $D_C$ are associated to the distortion in the image produced by the signature. If the image is expected to undergo a large compression, these values are large and consequently the image distortions are large. The block sites which are not selected according to (14) should have their parameters changed, in the signature casting stage, in order not to fulfill (15) or (16).

After checking the relations (15) or (16) and (1), the signature decision is taken based on the percentage of the image where the signature was found :

$$\frac{\sum_j s_j}{MR} > \frac{1}{2}, \quad (17)$$

where $s_j$ is the area size measured in pixels (8) where the constraints corresponding to the signature were detected, and $M \times R$ is the image size. In this way, the signature can be detected when provided only with a certain part of the signed image or in each frame of a signed image sequence.

## 5 EXPERIMENTAL RESULTS

The proposed algorithms were applied to embed different signatures on various images. The original "Baboon" image is shown in Fig. 1. The image Baboon signed by the algorithms described in (11) and (12) are provided in the Figures 2 and 4. The signature in these

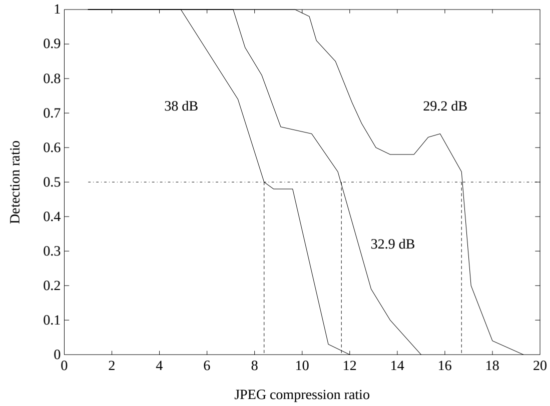


Figure 5: Linear DCT constraint.

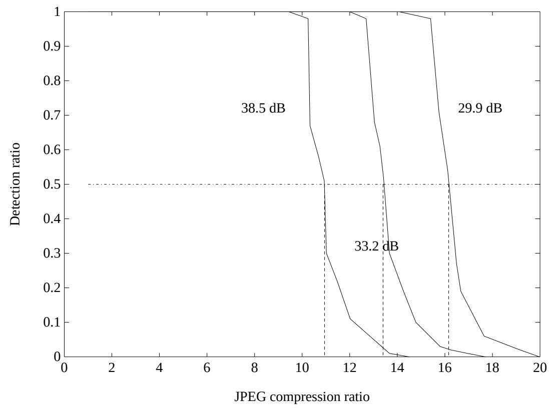


Figure 6: Circular DCT detection regions.

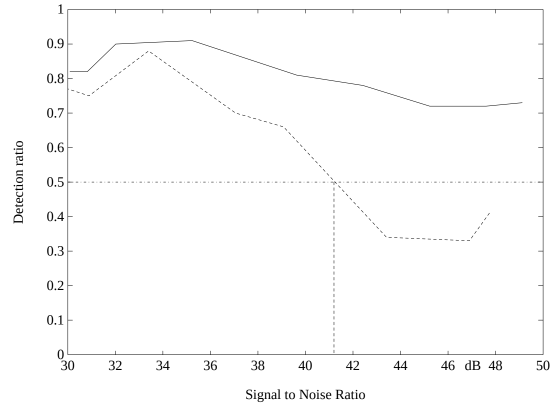


Figure 7: Signature detection after median filtering.

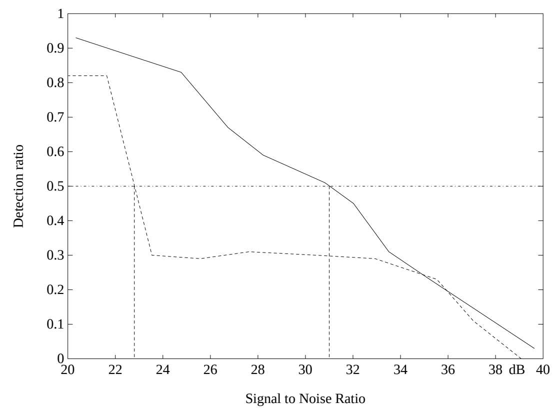


Figure 8: Signature detection after linear filtering.

images was correctly identified after the images were compressed by 13:1 and 18:1, respectively. The selected block sites in order to embed the signature are shown in Fig. 3. The signature resistance to JPEG compression and image filtering was tested as well. The plots representing the signature detection results when the images signed based on (11) or (12) are compressed by JPEG are shown in Fig. 5 and Fig. 6, respectively. The signature detection results after median and moving average filtering with a $3 \times 3$ pixels window are shown in Fig. 7 and Fig. 8. The dashed line represents the results when embedding linear DCT constraint and the continuous line represents the results when embedding circular DCT detection regions. The signature embedding levels $D_L$ and $D_C$ are represented by means of the respective distortion produced in the images, which is measured by the Signal to Noise Ratio between the signed and original image. The conventional decision criterion, i.e., detection ratio greater than 0.5, for the signature detection (17) is represented by a dash-dot line in all these plots. The algorithm which defines circular detection regions in the DCT domain (12) provides better signature robustness capabilities when compared to the linear constraint embedding algorithm (11). If the signatures are not designed to resist at big compression ratios, the image distortions will not be significant. The image quality degrades if the signatures are intended to resist at higher compression ratios.

## 6 CONCLUSIONS

The proposed watermarking algorithms selects certain pixel blocks in the image and a given constraint is embedded among their DCT coefficients. They define either linear or circular detection regions in the DCT domain. The digital signatures proved able to resist up to certain JPEG compression ratios and to representative filtering algorithms.

## References

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