Study of a hybrid deblocking post-processor based on watermarking

MARIE RAMON, FRANCOIS-XAVIER COUDOUX, MARC GAZALET, PATRICK CORLAY
IEMN Department OAE (UMR CNRS 8520)
University of Valenciennes
Le Mont Houy, 59313 Valenciennes Cedex 9
FRANCE

Abstract: - In this paper, we investigate a hybrid digital image post-processor for blocking artifacts reduction. The proposed post-processor exploits data hiding capabilities: blockiness visibility measurement is computed accurately at the encoder using both original and compressed data, and measurement results are embedded in the compressed picture by applying a steganographic technique in the DCT domain. Then, these are extracted from the watermarked image at the decoder stage, and used to apply adaptive post-filtering. By judiciously selecting which coefficients will be modified, one can control artifacts visibility/bit rate variations induced by embedding process, at payload expense. Tests are conducted and the results show a strong reduction of grid-noise in the reconstructed picture for a favorable CR range.

Key-Words: - Image compression, steganography, objective block impairment metric, adaptive deblocking filter.

1 Introduction
Digital image quality has become a very attractive area of research, and many efforts have been done in recent years in order to develop effective digital image quality/impairment metrics [1]. These metrics can be used to evaluate, monitor or further improve the performances of any image communication system, and can be classified into two categories: Full Reference (FR) metrics for which the original material is fully available, and Reduced Reference (RR)/No Reference (NR) metrics in the contrary case.

It is clear that FR metrics are most accurate, as they benefit from the knowledge of the original image data. Moreover, more computing time and power are generally available at the encoder. In particular, it should be of interest to exploit the results of an objective FR metric in the context of digital compressed image post-processing. In this case, the reduction of coding artifacts is performed adaptively, based on their perceptual relevance. A first possibility would be to copy measurement data in the file header, as JPEG standard, for example, may contain additional features [2]. But this is at the expense of the total bit rate.

In this paper, we experiment an original proposal of a hybrid post-processor for the reduction of coding artifacts in JPEG-coded color images. We restrict ourselves to the reduction of blocking artifacts, because blocking effect constitutes the main drawback of most current image compression standards. Indeed, it has been found to be very objectionable to the human viewer, due to the perceptual characteristics of this particular distortion [3]. The proposed post-processor exploits the capabilities of data hiding [4,5]. The measurement of blockiness visibility is computed more precisely at the encoder using both original and compressed data, and measurement results are embedded in the compressed picture. Then, these are extracted from the watermarked image at the decoder stage, and used to apply adaptive post-filtering. By judiciously selecting which coefficients will be modified, one can control artifacts visibility/bit rate variations induced by embedding process, at payload expense. Tests are conducted and the results show a strong reduction of grid-noise in the reconstructed picture for a favorable CR range.

2 The proposed hybrid post-processor
The proposed scheme is detailed in Fig. 1. It should allow us to use, at the decoder level, information depending on the original image characteristics which the receiver cannot have access to otherwise. First, a FR objective metric is applied at the encoder level in order to compute the block visibility in the JPEG-coded image. So, we determine each coded image block boundary value to yield a binary perceptual distortion map. We wish to use this map to guide local filtering at the decoder level. Coded image will be modified to carry this information, hence a first constraint: consequences over bit rate might remain minimal to keep the compression benefits. Finally, the decoder receives a marked image and if unable to retrieve and benefit from the mark, will directly broadcast it. Thus compatibility matters imply an invisible embedding method. In the contrary case, the mark is extracted and used in order to perform adaptive post-filtering of visible block boundaries. The following
sections describe the different parts of the proposed solution.

**EMITTER / ENCODER:**

Original image \(\xrightarrow{\text{JPEG encoding}}\) Coded image \(\xrightarrow{\text{Bit rate}}\) Insertion \(\xrightarrow{\text{Marked image}}\) Block-edge impairment metric \(\xrightarrow{\text{Binary perceptual distortion map}}\) EMITTER / ENCODER:

**CONVENTIONAL RECEIVER:**

Marked image \(\xrightarrow{\text{JPEG decoding}}\) Marked image

**MODIFIED RECEIVER / DECODER:**

Marked image \(\xrightarrow{\text{Binary perceptual distortion map}}\) Retrieval \(\xrightarrow{\text{JPEG decoding}}\) Filtering \(\xrightarrow{\text{Corrected image}}\)

Figure 1: General scheme of the complete hybrid post-processor.

### 2.1 Blocking effect metric

Among the various existing FR metrics, the Perceptual Blocking Distortion Metric (PBDM) [6] is parameterized using subjective quality assessment data recently provided by the VQEG. It is shown that this digital image quality metric is strongly correlated with the mean opinion scores of human observers. The PBDM is formulated based on the observation that blocking artifacts are noticeable only in certain regions of a picture: the lower spatial activity of surrounding pixels will be, the more visible they will appear. The decomposition and the distortion measurement are based on a complete vision model which takes into account the multi-channel structure of the HVS, contrast sensitivity and pattern masking. A method to segment blocking dominant regions is devised, and perceptual distortions in these regions are finally summed up to form an objective measure of blocking artifacts. In the present case, a binary perceptual distortion map is generated based on PBDM computed from the luminance \((Y)\) component. This map represents the thresholded perceptual distortion at every block boundary location. The value equals to one when the block boundary is visible and zero elsewhere. These data are embedded in the compressed image and will further be used to reduce the most visible block artifacts at the decoder.

### 2.2 Data hiding

Characteristics of an effective marking system depend on the application constraints. There exists a complex trade-off between robustness [7], data payload [8] and fidelity, which is often tied to the targeted application. Here, we are much more concerned about steganography: fidelity and payload are mostly required while the robustness constraint is low. Data existence is supposed to be unknown to the viewer and a successful attack would just consist in information detection. Furthermore, only coded picture is available at the decoder, data must be retrievable without the need of extra information. The embedding scheme must be public, and is applied to the picture by a substitutive technique. Among the different public embedding schemes, we retained the one described in [9] for its effectiveness.

The algorithm substitutes one bit of the mark noted here \(Is\) to the Least Significant Bit (LSB) of the selected DCT quantized coefficient, also called carrier, we denote \(C_q(u,v)\). Selection is achieved by thresholding: we determine a threshold \(T\) below which we consider that \(C_q(u,v)\) must not be modified. Finally, data hiding is done according to the following equation:

\[
C_q(u,v) = \begin{cases} 
  C_q(u,v) & \text{if } C_q(u,v) \leq T, \\
  |C_q(u,v)| & \text{if } C_q(u,v) > T \text{ and } \text{LSB}(C_q(u,v)) = Is, \\
  |C_q(u,v)| + 1 & \text{if } C_q(u,v) > T \text{ and } \text{LSB}(C_q(u,v)) \neq Is 
\end{cases}
\]

Notice that the capacity is one bit per modified coefficient but the average error is below (case \(Is = C_q(u,v)\)). A marked coefficient remains above the threshold, which will allows its identification as long as the research order is the same at both encoder and decoder levels. Retrieval is achieved by a simple reading of the received coefficient LSB. Embedding occurs before run length and entropy encoding, once the 8x8 pixels have been transformed and quantized. So the side information cannot be corrupted by JPEG compression. Because the host image is already compressed, it contains compacted information, hence a smaller carrier amount, which makes the constraints harder to meet. We have to judiciously select which coefficients will be most alike to carry the message, based upon perceptive criteria. It is clear that modifying DC value would affect the whole block tint and would consequently be too visible. Furthermore, inserting information in HF coefficients, whose magnitude is low or even null, would introduce not only a perceptible distortion (higher quantization step) but also an increase in bit rate during run length coding (interrupted zero sequence).

Following JPEG principle, coefficient research is performed using a zigzag scan from middle-high frequencies. Concerning the threshold adaptation to the coefficient rank, each threshold \(T(u,v)\) is chosen to be inversely proportional to the corresponding quantization
step size $Q(u, v)$, used for JPEG encoding. The more the image will be compressed, the more the step size and threshold will be high, insuring the induced distortion will be proportionally lower. Hence the proposed relation:

$$T(u, v) = k / Q(u, v)$$  \hspace{1cm} (2)

The parameter $k$ should be tuned for both luminance and chrominance components. The values $k = 31$ for the luminance and $k = 41$ for chrominance components have been determined experimentally.

As the human eye is more sensitive to luminance than chrominance, data is embedded in chrominance first. Moreover, the mark will be ordered, mark bits related to the center prior to mark bits related to sides of the picture in a spiral scan, before insertion takes place. As we chose to avoid distorting luminance to the point it becomes visible, we cannot guarantee the data payload will be large enough. In this case, borders of the picture might be filtered unconditionally.

2.3 Adaptive post-filtering

Once the metric has been retrieved, the binary location map values are used to guide the coded picture post-processing. In [10], the authors propose a space-variant low pass filter which smoothes pixel values at visible block boundaries. We adapted the process to make it work in two symmetrical steps over the two neighboring blocks (Fig. 2).

![Figure 2: Visible boundary filtering.](image)

3 Experimental results

Extensive tests have been led over a database constituted of seven images of various characteristics, in the YUV 4:2:2 format. These images have been compressed for different compression ratios (CR) by means of the JPEG algorithm. In order to vary the CR, the luminance and chrominance default quantization matrices are multiplied by a so-called quantization factor, noted $Q_f$. Studied CR range is bounded by:

- $Q_f = 0.2$, corresponding to an average CR around 10:1, hence a nearly broadcast quality,
- $Q_f = 2$, corresponding to an average CR around 45:1, hence a highly distorted signal.

We present average results calculated over the whole database. A simplified version of PBDM has been implemented for scheme evaluation [11] and adapted to return in-between results, corresponding to the metric value at each vertical and horizontal block boundary in the Y component. In order to make the metric more accurate, the original image is used for impairment selection. If a boundary belongs to both coded and original images, it will be considered as a real edge and removed from the final map, avoiding false block detection. A metric value above one indicates a more severe block edge artifact and a lower value implies a blurring artifact in the luminance component. An original image average metric is around 1, whereas a coded image metric can reach a value of 3 for CR around 50:1.

3.1 Fidelity

One of the constraints concerns the visual quality of the compressed image after data embedding. Fidelity refers to equivalent quality of both modified and original images. Using appropriate embedding parameters, we insure that image quality is preserved: cases showing the most perceptible degradations have been experimentally determined and avoided, so that the tolerated distortion is hardly noticeable.

The common PSNR measure is used, although badly correlated with human viewer opinion: PSNR considers as a noise any pixel change from its original value, however visible it could be. Figure 3 shows the difference between the PSNR values of the compressed image before and after the embedding process for the Y, U, V components respectively. We notice that, for moderate CR ($Q_f$ around 1), the PSNR decreases up to 0.5 dB for Y, and less than 1 dB for the chrominance components. However, it should be noted that this decrease of the PSNR values is not much annoying visually, and is well compensated after blocking effect removal at the decoding stage. Of course, we notice that the more the image is compressed, the more embedding will alter its quality. The rate of modified non zero coefficients gets higher, so does the value by which they are modified (the quantization step). DCT patterns accentuation after embedding follows quantization step size magnitude; it rises as the CR increases.
3.2 Bit rate variations
Embedding modifies the DCT coefficient values and thus the corresponding bit stream after run length and entropy coding. Figure 4 represents the rate variations due to embedding process. We note that the output bit rate remains negligible (lower than 2% of the total image file size) for a wide CR range. As a comparison, an alternative would be copying data in the file header. The « extra picture information » field data is organized in bytes preceded by a 1 and the last byte to transmit is preceded by one 0, which yields a rate increase proportional to image size. In this case, the bit rate increase varies from 2% to more than 5% of the total file size for the same CR range.

Figure 4: Bit rate increase due to embedding process for varying quantization factors.

3.3 Data payload
Yet, using the given parameters, quality and bit rate are preserved but the whole mark is not always inserted and transmitted. If the host image capacity is not large enough, part of the values will not be received and retrieved, hence an error rate at the decoder level. It is null for an image containing many HF patterns and can reach 30% for images containing more uniform areas. Although around 20% in average, the error rate corresponds to the loss of data end. Because the mark contains ordered data, information that will be lost concerns image sides which will be filtered unconditionally, smoothing some original image details. In this situation, filtering will be superfluous only half the time, case of non visible boundaries.

One can reduce and even annul this error rate by lowering insertion thresholds or authorizing more coefficients to be examined (marking more BF coefficients), but we allow marking to modify more sensitive areas, hence more bit rate and perceptibility problems. Conversely, if the fidelity criteria has to be strictly respected, one can obtain a perfectly invisible insertion but with half the payload.

3.4 Correction efficiency
The study aims at improving digital image quality under two main constraints: bit rate preservation and imperceptibility. We noticed that these constraints limited the scheme data payload; receiver cannot have access to the whole information. Thus, we consider in the following the improvement of the overall visual quality due to adaptive filtering of the decoded image.

We verify that the post-processor becomes suitable for CR above 20:1 even if PSNR values may slightly decrease (as we yet noticed, PSNR doesn't give the most representative results of perceived distortion). More precisely, we are heading for blocking effect concealment. If we calculate the average PBDM of the post-processed image, its value nearly reaches the original image one, meaning the blocking effect has been consequently reduced (Fig. 5).

Visually, embedding distortion is hardly perceptible for CR ranging from 20:1 to 40:1. We can notice, if the case arises, some of the coding artifacts are put in relief, such as reinforced DCT patterns in luminance and/or in chrominance. Concerning correction, uniform areas grid noise has been reduced, block boundaries filtered where they are the most disturbing. Moreover, original edges are preserved thanks to the use of the FR metric values. Despite de-blocking may give a lower PSNR, it offers a higher-quality subjective viewing experience, as seen in Fig. 6.
Figure 5: Perceptual Block Distortion Metric of original (-), coded (*) and post-processed (°) images for varying quantization factors.

4 Conclusion

In this paper, we have tested a new hybrid post-processing scheme designed to remove blocking artifacts in JPEG coded images. Block edge visibility is evaluated at the encoder using the PBDM full-reference metric, and measurement results are embedded in the compressed picture. At the decoder stage, these are extracted from the received image, and used to apply adaptive post-filtering, in order to smooth the most noticeable block boundaries. We can define a CR favorable application range varying approximately from 20:1 to 40:1. For this CR range, the embedding process preserves fidelity with little bit rate increase. At the decoder, blocking effects are efficiently smoothed; hence the visual quality of the reconstructed image is improved. For higher CR, insertion becomes too perceptible / embedded data size becomes too small to allow a global image quality increase anymore, modification of the remaining information is too visible.

By judiciously selecting the altered coefficients and tuning their respective threshold, one can control the visibility of artifacts / the bit rate variation induced by embedding process. There is a compromise to make between fidelity and data payload.

References:

Figure 6: Original (a), compressed with: $Q_f = 1.5$ (b), marked (c) and corrected (d) images.