Minimizing Data-Hiding Noise in Color JPEG Images by Adapting the Quantization

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Abstract

The data-hiding is an application of the steganography. Its purpose is to embed a large amount of data in images in an invisible way. Several methods are robust to the JPEG compression algorithm. In the present paper, we investigate the noise they induce on images and propose an improvement to make it minimal with regard to the transparency.

Introduction

The steganography is now become an important field of investigation in image processing. Its main application is the watermarking which aims at ensuring image security or authentication. The robustness is predominant since the embedded mark is subjected to malicious attacks. Several methods has been developed under such assumptions as, for instance, spread-spectrum [4] or QIM [3]. Another use of steganography is the data-hiding. It is not dedicated to security or authentication, but rather to the embedding of a huge quantity of data in images. Those data can be totally independent from the image content as well as they can enrich it. Important features are here the embedding capacity and the transparency. The capacity is related to the length of the hidden message and the transparency is the ability of data to be invisible to human perceptions. However, data-hiding methods have to be robust to usual transformations such as the compression.

The compression standard for images is currently the JPEG one [6]. It reduces the image information in an appropriate color space, the YC_rC_b one, and in an appropriate frequency domain, the DCT one. Several data-hiding methods allow to be robust against the JPEG compression. In particular, the simplest ones proceed similarly as JPEG and then hide data in the frequency coefficients by substitution of their *less significant bit* (LSB) [1, 2, 5].

In the present paper, we investigate the noise induced by such data-hiding methods in images. In fact, the usual substitution is not optimal with regard to the transparency. We introduce then an improvement of the data-hiding method by adapting the quantization step to it. Our solution is optimal in this regard.

The paper is organized as follows. First we begin with some recalls on the JPEG compression and data-hiding methods robust to it. We quantify the induced noise in images and define what is the optimal data-hiding solution with regard to the transparency. We then present how to reach it and show with theoretical considerations and experimental results the improvement of the transparency.

JPEG compression

The JPEG compression of color images [6] induces two losses of information which are due to the color space transformation and during the transformation to the frequency domain. The JPEG compression process begins with a transfor-

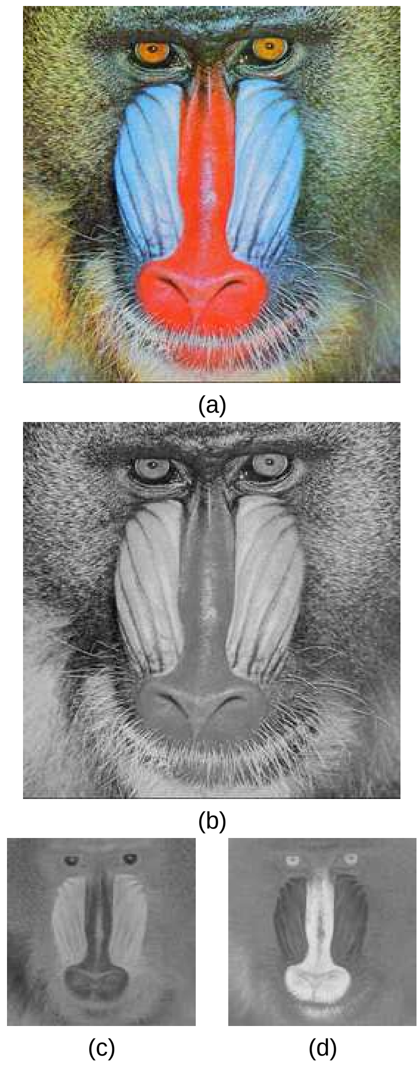


Figure 1. *Decomposition of an image in color space YC_rC_b and sub-sampling of the chrominance informations. (a) Original image, (b) luminance information, (c) C_r component information, (d) C_b component information.*

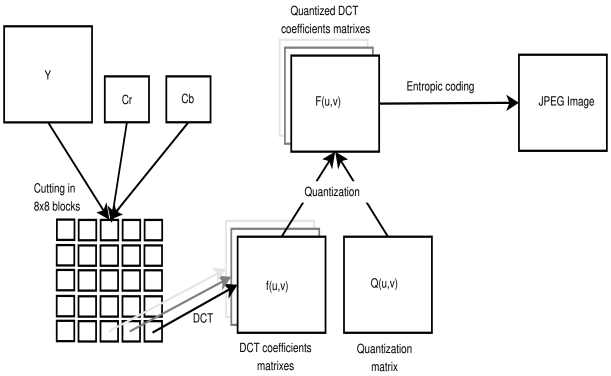


Figure 2. *The JPEG compression process.*

mation from the usual color space *RGB* to the YC_rC_b one. This color space has the advantage to concentrate the main part of the image information in the luminance component Y. Thereby, the chrominance components, C_r and C_b, could be sub-sampled. The image size is thus reduced without being to much degraded. In Figure 1, the baboon image (a) is decomposed in its luminance information (b) and its both chrominance informations (b) and (c). One see that images (a) and (b) are very similar as mentioned above.

The JPEG compression works then in the frequency domain induced by the *Discrete Cosine Transform* (DCT). Similarly to the selected color space, this frequency domain concentrates the information. In fact, the high frequencies are less informative than the low ones. The quality factor selected by the user controls the quantization coefficients $Q(u,v)$. In the quantization step, the division of DCT coefficients $f(u,v)$ by $Q(u,v)$ are rounded to the closest integer to give *quantized DCT coefficients* $F(u,v)$. Information is lost in all frequencies but mainly in high ones since they are less informative. The quantization step can be summarized by:

$$F(u,v) = \left[\frac{f(u,v)}{Q(u,v)}\right], \tag{1}$$

where $[x]$ denotes the closest integer to x.

The difference between the value of a DCT coefficient $f(u,v)$ before the quantization and the one computed after the quantization, that is, the quantized DCT coefficient $F(u,v)$ multiplied by $Q(u,v)$, corresponds to the information lost during the quantization step. It is bounded as follows:

$$0 \leq |F(u,v) \times Q(u,v) - f(u,v)| \leq \frac{1}{2}Q(u,v). \tag{2}$$

The main loss of information in the JPEG compression process is during the quantization step.

Finally, an entropic coding compresses the information on the frequency domain. By using Huffman code, the quantized DCT coefficients are transformed in a more compact form. In particular, null coefficients created by the quantization greatly increase the compression. The whole process is summarized in Figure 2.

Data-hiding robust to JPEG compression

The usual way to be robust to JPEG compression is to work in the same frequency domain, namely the DCT one. The simplest methods, presented below, substitute the LSB of quantized frequency coefficients by bits to be embedded.

Data-hiding methods

A first possible method is the data-hiding in the Direct Current coefficients (DC coefficients) $F(0,0)$. It is based on the knowledge of these particular coefficients. Indeed, they are directly related to the mean intensity of considered pixels. Thus, a variation of the DC coefficient will be uniformly spread on the block. A secret bit is embedded in each DC coefficient by substitution of the LSB.

This method presents two advantages: its simplicity and its robustness. The mean intensity of a block is a quite global indicator and resists well to pixel modifications. On the contrary, the capacity is low since only one bit could be embedded in each 8×8 block. The secret information is limited to 0.1% of the original color image size (1.5 Kbytes for an image of size 256×256 pixels).

In order to improve such a limitation, the Jpeg/Jsteg method [2] embeds one secret bit in each quantized DCT coefficient with an absolute value greater than 1. This restriction aims at preserving the null coefficient values and, thus, at preserving a good compression rate. As expected, the capacity is improved and increases up to 6.5% of the original color image size (96 Kbytes for an image of size 256×256 pixels). From a practical point of view, this rate is far from being reached and mainly depends on the image content and the quality factor of the JPEG compression.

Characteristic points

Both methods are very close. In particular, they both hide data after the quantization by substituting the LSB. Embedding frequency coefficients $F_1(u,v)$ are computed as follows:

$$F_1(u,v) = F(u,v) - F(u,v) \textit{ mod } 2 + b_t, \tag{3}$$

where $x \textit{ mod } y$ denotes the rest of the integer division of x by y, and b_t is the bit to be embedded. Modifications induced on the compression process are shown in Figure 3. In fact, the data-hiding step is just added before the entropic coding. So, the data-hiding provides an additional loss of information after the quantization. If the secret bit is different from the LSB, two integers should be considered: the one just greater and the one just smaller than the integer quantized DCT coefficient $F(u,v)$. As it is impossible to tell one from the other because they are both at the same distance from the current value, the substitution arbitrarily selects one of them. For those data-hiding methods, the information loss can be express by the following inequalities:

$$\begin{aligned} 0 \leq & \quad |F_1(u,v) - F(u,v)| & \leq 1, \\ 0 \leq & \quad |F_1(u,v) \times Q(u,v) - f(u,v)| & \leq \frac{3}{2}Q(u,v). \end{aligned} \tag{4}$$

Minimizing the noise induced on images

In the previous section, we have seen that data are usually embedded after the quantization by an arbitrary choice of the frequency coefficient. The solution in not optimal with regard to the transparency because of this arbitrary choice. We now focus on the optimal solution.

To be optimal, a DCT-based data-hiding method by substitution of the LSB has to respect two conditions:

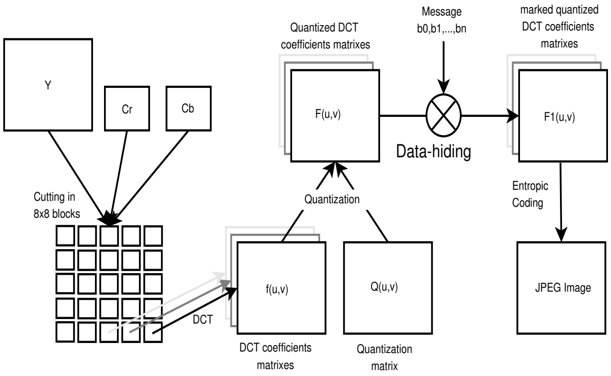


Figure 3. *DCT-based Data-Hiding by substitution of the LSBs.*

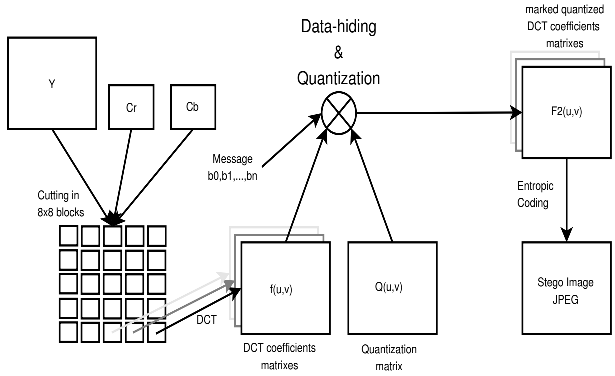


Figure 4. *Adaptation of the quantization to the data to be embedded.*

- the integer value resulting of the computation $F_2(u,v)$, multiplied by the corresponding $Q(u,v)$, has to be as close as possible to $f(u,v)$,
- the LSB of $F_2(u,v)$ has to be equal to the bit b_t to be embedded.

Optimal solution

A quantized DCT coefficient not rounded, namely the division of $f(u,v)$ by $Q(u,v)$, is a floating value. The two nearest integer values are the one just smaller and the one just greater. These two integers are consecutive and have not the same LSB. If we select the one with LSB equals to the bit b_t to embed, we satisfy the two conditions mentioned above. Indeed, we thus choose the closest integer to the ratio $f(u,v)$ over $Q(u,v)$ such that b_t is its LSB.

Adapting the quantization step to the data-hiding is formalized as follows:

$$F_2(u,v) = \begin{cases} \left\lfloor \frac{f(u,v)}{Q(u,v)} \right\rfloor \text{ if } \left\lfloor \frac{f(u,v)}{Q(u,v)} \right\rfloor \mathit{mod}\ 2 = b_t \\ \\ \left\lceil \frac{f(u,v)}{Q(u,v)} \right\rceil \text{ if } \left\lceil \frac{f(u,v)}{Q(u,v)} \right\rceil \mathit{mod}\ 2 = b_t \end{cases} . \quad (5)$$

The modifications induced on compression process are shown in Figure 4. Both lossy operations, the quantization and the data-hiding are combined in the same stage. Consequently, the data-hiding meets requirements mentioned above and the transparency is optimal. The loss information can be expressed by the following inequality:

$$0 \leq \quad |F_2(u,v) \times Q(u,v) - f(u,v)| \quad \leq Q(u,v). \quad (6)$$

Let us now apply this adaptation on a simple example.

Example 1 *One consider the following case:*

- *Secret bit,* $b_t = 1$
- *Quantization factor of the coefficient,* $Q(u,v) = 10$
- *Coefficient value,* $F(u,v) = 96$
- *Quantized coefficient value,*
  $F(u,v) = \left[\frac{96}{10}\right] = 10$

With the common data-hiding approach, after quantization, the value of the quantized DCT coefficient embedding the secret bit, b_t *is,* $F_1(u,v) = 11$.

Both closest values of the DCT coefficient which will be integer values after quantization are 90 and 100. With our adaptation we choose the value which has its LSB equal to the secret bit, b_t. *Here,* $F_2(u,v) = 9$.

The two approaches give different results. The adapted quantization leads to the closest value from the DCT coefficient quantized and not rounded, that is, 9.6.

Theoretical results

The first Table presents theoretical results. It highlights the different case which can happen. In the first line, cases are determined in function of the closest integer to the ratio $f(u,v)$ over $Q(u,v)$. $\lceil x \rceil$ denotes the closest integer greater than (or equal to) x and $\lfloor x \rfloor$ the one smaller than (or equal to) x. In the second line, they are determined in function of the LSB of $F(u,v)$, and in the third one, in function of the bit b_t to be embedded. The next three lines in this first Table give the variation between the ratio $f(u,v)$ over $Q(u,v)$ and the value in output respectively when one only compresses the image, hides data in the usual way or hide them with our optimal solution. Finally, the last line compares the both embedding method. Our method is confirmed to be better then the usual one in any case.

Experimental results

Investigations in the frequency domain give qualitative results on our improvement with regard to the transparency. To obtain quantitative results, we experiment on images.

We introduce before the indicators we use. The *Mean Square Error* (MSE) gives information about the differences between pixels. It is expressed as:

$$MSE = \frac{\sum_{i=0}^{N-1} \sum_{j=0}^{N-1} (p(i,j) - p'(i,j))^2}{N^2}, \quad (7)$$

where $p(i,j)$ and $p'(i,j)$ are the pixel at position (i,j), respectively in the original image and in the marked one. This indicator is applied on the three components Y, C_r and C_b and we obtain three values, MSE_Y, MSE_{C_r} and MSE_{C_b}. From this point, we compute the Peek Signal on Noise Ratio (PSNR) as follows:

$$PSNR = 10 \log_{10} \left(\frac{255^2}{MSE_Y + MSE_{C_r} + MSE_{C_b}} \right). \quad (8)$$

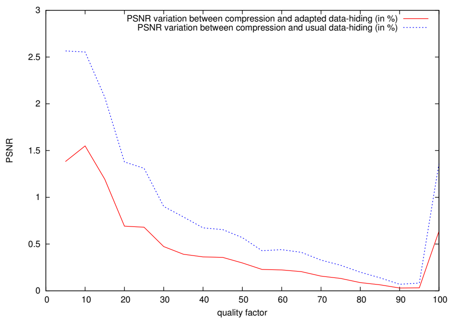
PSNR gives an idea of the objective quality of an image relatively to another one. The higher it is, the closer both images

$\left[\frac{f(u,v)}{Q(u,v)}\right]$	$\left\lfloor\frac{f(u,v)}{Q(u,v)}\right\rfloor$				$\left\lceil\frac{f(u,v)}{Q(u,v)}\right\rceil$			
$\left\lfloor\frac{f(u,v)}{Q(u,v)}\right\rfloor\%2$	0		1		0		1	
b_t	0	1	0	1	0	1	0	1
Compression: $\lvert\Delta F(u,v)\rvert$	δ				$1-\delta$			
After quantization: $\lvert\Delta F_1(u,v)\rvert$	δ	$1-\delta$	$1+\delta$	δ	$1-\delta$	$2-\delta$	δ	$1-\delta$
Adapted quantization: $\lvert\Delta F_2(u,v)\rvert$	δ	$1-\delta$	$1-\delta$	δ	$1-\delta$	δ	δ	$1-\delta$
Gain: $\lvert\Delta F_1(u,v)\rvert-\lvert\Delta F_2(u,v)\rvert$	0	0	$\mathbf{2\delta}$	0	0	$\mathbf{2-2\delta}$	0	0

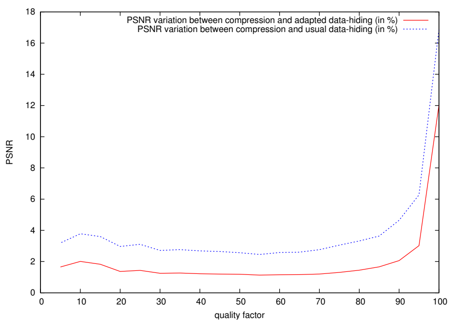
δ,floating part of $\frac{F(u,v)}{Q(u,v)}$: $\delta = \frac{f(u,v)}{Q(u,v)} - \left\lfloor\frac{f(u,v)}{Q(u,v)}\right\rfloor$

Comparison of the variations induced by data-hiding after the quantization and adaptation of the quantization.

(a)



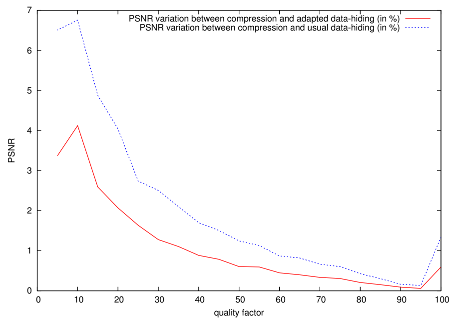
(b)



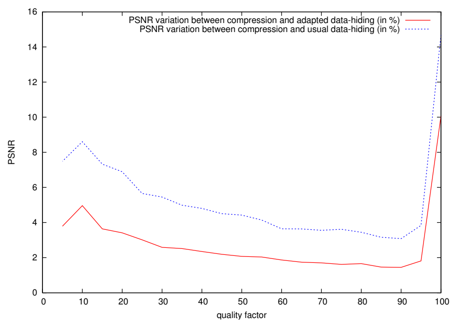
(c)

Figure 5. *Comparison of noise induced by data-hiding on the baboon image. (a) The baboon image, (b) data-hiding method in DC Coefficients, (c) Jpeg/Jsteg data-hiding method.*

(a)



(b)



(c)

Figure 6. *Comparison of noise induced by data-hiding on the peppers image. (a) The peppers image, (b) data-hiding method in DC Coefficients, (c) Jpeg/Jsteg data-hiding method.*

Comparison of quality between marked images obtained by Jpeg/jsteg or DC standard methods and adapted ones for different quality factors (50% and 100%).

	PSNR(dB)			
	standard Jpeg/Jsteg		adapted Jpeg/Jsteg	
	baboon	peppers	baboon	peppers
QF=100 %	46.32	47.18	48.32	49.15
QF=50 %	25.72	28.77	26.07	29.44
	standard DC		adapted DC	
	baboon	peppers	baboon	peppers
QF=100 %	53.40	53.39	53.78	53.78
QF=50 %	26.23	29.68	26.30	29.87

are. In our case, the PNSR quantifies the difference between the original image and the compressed and marked one.

We have implemented Jpeg/Jsteg [2] and DC data-hiding methods with the adapted quantization. The second Table 2 presents results in term of PSNR for quality factor of 100% and 50% when we embed data in both images baboon and peppers. The transparency improvement is more important with the Jpeg/Jsteg method than with the DC one. As more frequency coefficients embed secret bits, the data-hiding noise plays a main role in the global loss of information and thus its reduction is influent on the image quality. In the same way, the PSNR variation is greater with a quality factor of 100%. The quantization does not degrade much the image and the main loss is still the data-hiding noise. In Figures 5 and 6, comparisons between compressed images and compressed and marked images are done in term of percentages of quality degradation. Under this consideration, the gain seems close to be constant. Indeed, the loss in percents is reduced by about an half by the adapted quantization. A unexpected fact appears when the quality factor is very high. One see an abrupt decreasing of the PSNR just when the quality factor decreased from 100%. At this limit value, JPEG compressed image and the original one are very similar. The smallest variation has then an important impact on it. As soon as the quantization really applies, images are less sensible to the data-hiding noise and the quantization losses become predominant.

The quality factor of the JPEG compression determines this improvement. With a high quality factor, errors induced by quantization stay small and the gain obtained is immediately visible. On the contrary, with lower quality factor, the gain is too small compared to the quantization losses.

Conclusion

Focusing on the DCT-based data-hiding methods which embed secret bit by substitution of the LSB, we have shown that they are not optimal according to the transparency. In the present paper, we have proposed an improvement which minimizes the data-hiding noise. For that purpose, we combined both steps of the quantization and the data-hiding in the same stage. The quantization is then adapted to the data to be embedded. The quality relatively to the original image is improved and our solution is optimal in regard of the transparency.

References

[1] C.-C. Chang, T.-S. Chen and L.-Z. Chung. A Steganographic Method Based upon JPEG and Quantization Table Modification. In *Information Sciences*, volume 141, pages 123–138, 2002.

[2] C.-T. Hsu and J.-L. Wu. Hidden Digital Watermarks in Images. In *IEEE Transaction on Image Processing*, volume 8, pages 58–68, 1999.

[3] Brian Chen and Gregory W. Wornell. Quantization index modulation: A class of provably good methods for digital watermarking and information embedding. *IEEE Transactions on Information Theory*, 47(4):1423–1443, 2001.

[4] Ingemar J. Cox, Joe Kilian, T. Leighton, and Talal Shamoon. Secure spread spectrum watermarking for images, audio and video. In *Proccedings IEEE ICIP*, volume 3, pages 243–246, 1996.

[5] H.-W. Tseng and C.-C. Chang. High Capacity Data Hiding in JPEG-Compressed Images. *Informatica*, 15(1):127–142, 2004.

[6] G. Wallace. The JPEG still picture compression standard. *Communication of the ACM*, 34(4):31–44, Apr. 1991.

Author Biography

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