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ABSTRACT

In this paper, we propose a method to embed the color information of an image in its corresponding grey-level image. The objective of this work is to allow free access to the grey-level image and give color image access to secret key owners. This method is made of two steps which are the color image decomposition (in a grey-level image and its associated color information) and the data-hiding. The main contribution of this papper is the energetic function proposed to model the decomposition of the color image. The optimization of the proposed energetic function leads to the obtention of an *index* image and a color palette. The good properties of that decomposition are an *index* image which is similar to the luminance of the color image and a color palette which is well suit for the data-hiding. The obtained results confirm the model quality.

***Index Terms** (from IEEE keyword list)*— Image processing, Image transmission, Data security, Data transmission, Color.

1. INTRODUCTION

Nowadays, only a few algorithms have been proposed that give both a free access to low-quality images and a secure access to the same images with an higher quality. Our proposed solution is built on a data-hiding method. The image may be freely obtained but its high quality visualization requires a secret key. More precisely, in our solution, a grey-level image is freely accessible but only secret key owners may rebuild the color image. Our aim is thus to protect the color information by embedding this information in the grey level image. Note that this work is though to be used to give a limited access to the private digital painting data-base of the Louvre Museum of Paris, France.

In order to obtain a grey-level image embedding its color information, we decompose a color image in an *index* image and a color palette. The color palette is then hidden in the *index* image. The *index* image should be similar to the luminance of the color image, the embedding process should be of week magnitude and the color palette should be cleverly ordered. The originality of this paper is to propose a solution for this very constrained decomposition. Thus, the main contribution is the energetic function proposed to model the decomposition of the color image. The optimization of the proposed energetic function leads to the obtention of a well suit *index* image and a well ordered color palette.

Many works propose solutions to hide information by using the decomposition of a color image in an *index* image and a color palette. The data-hiding may occur in the *index* image [1] or in the color palette [2, 3]. Nevertheless, none of those techniques tries to protect the color information by hiding the color palette in the *index* image. Only the previous work of [4] protect the color information by hiding the color palette in the *index* image. Authors of [4] sort the colors of the color palette in order to get an *index* image which is near of the luminance of the original color image and in the same time they get a color palette whose consecutive colors are close. In this paper, the approach is completely different and relies on a function optimization of the global problem formulation.

Other works such that [5, 6, 7] based on wavelet decomposition and sub-band substitution propose solutions to embed the color information in a grey-level image. Their areas are perceptive compression and image authentication for [5, 6] and image printing for [7]. Even if those techniques embed the color information, their approach and their purpose are clearly different from that exposed in that paper.

In section 2, we present the proposed energetic model. Section 3 deals with the secured data-hiding method. In section 4, results are presented and are compared to those of [4].

2. ENERGETIC MODEL

The goal of the first step is to find an *index* image and a color palette with the following constraints:

- the *index* image should be close from the luminance of the original color image,
- the color quantized image should be close from the color image,
- and the color palette should own consecutive couples of close color.

In [4] the proposed approach was made of three points: a quantization, a color palette re-ordering and the data-hiding.

The major contribution lied on the definition of a *running layer algorithm* which aim was to run the RGB color space in order to find a re-organized color palette. This previous approach is extremely rapid but the obtained *index* image is strongly contrasted in regard of the luminance of the original color image.

In this paper, we propose a solution to obtain a visually more pleasant *index* image and to obtain a better quality equilibrium between the *index* image and the quantized color image. The proposed approach is completely different since quantization and color palette ordering are made in only one step, the color palette constraint is weaker and the main contribution lies on the modeling and the optimization of an energetic model.

As explain previously, the problem of the computation of a color palette made of couples of close colors and an *index* image similar to the luminance may be expressed by three constraints. Mathematically this comes to found the K colors $C(k)$ (C is the color palette) and the $P_{i,k}$ ownership values giving the degree of belongingness of a pixel i to the k^{th} color. Note that $P_{i,k}$ belongs to $[0,1]$ and are named fuzzy membership values in fuzzy c-mean clustering approach [8]. Also note that the $P_{i,k}$ give indirectly the *index* image such that: $Index(i) = \arg_k \max_k P_{i,k}$

Thus, we are looking to minimize the above energetic model in order to obtain $\forall i \in [1,N]$, $\forall k \in [1,K]$, $P_{i,k}$ and $C(k)$:

$$\begin{aligned} E = & \underbrace{\sum_{i=1}^{N}\sum_{k=1}^{K} P_{i,k}^{m}(C(k)-I(i))^2}_{first\ term} \\ & + \underbrace{\lambda_1 \sum_{i=1}^{N}\sum_{k=1}^{K} P_{i,k}^{m}(Y(i)-k)^2}_{second\ term} \\ & + \underbrace{\lambda_2 \sum_{k|k\in[1..K]\ and\ k\ is\ odd} (C(k)-C(k+1))^2}_{third\ term}, \end{aligned} \quad (1)$$

with I the color image, Y the luminance image, $\lambda 1$ and $\lambda 2$ two scalar values and $m \in]1,\infty[$ the fuzzy coefficient tuning the equi-probability degree[1].

The first term is expressing the constraint of color quantization. The aim is to found the best representative K colors. The second term stand for getting the *index* image the nearest to the luminance image Y. The last term constrain couples of consecutive color from the palette to be close.

The minimization of Equation 1 such that:

$$\{P_{i,k}, C(k)\} = \underset{\{P_{i,k},C(k)\}}{\arg} \min E, \quad (2)$$

is performed iteratively in a two steps loop as in conventional fuzzy c-mean algorithms. In the first step, colors $C(k)$ are updated, given $P_{i,k}$, by solving the linear system below:

$\underline{\forall k\ odd:}$

$$(\lambda_2 + \sum_{i=1}^{N} P_{i,k}^{m}) \times C(k) - \lambda_2 \times C(k+1) = \sum_{i=1}^{N} P_{i,k}^{m} I(i),$$

$\underline{\forall k\ even:}$

$$-\lambda_2 \times C(k-1) + (\lambda_2 + \sum_{i=1}^{N} P_{i,k}^{m}) \times C(k) = \sum_{i=1}^{N} P_{i,k}^{m} I(i). \quad (3)$$

In the second step, $P_{i,k}$ (with m=2) are updated given the colors $C(k)$ with:

$$P_{i,k} = \frac{\left(\sum_{l=1}^{l=K} \frac{1}{2\times((C(l)-I(i))^2+\lambda_1(Y(i)-l)^2)}\right)^{-1}}{2\times((C(k)-I(i))^2+\lambda_1(Y(i)-k)^2)} \quad (4)$$

Mathematical details are given in the Appendix.

3. SPATIAL DATA HIDING METHOD

The methods in spatial domain embed directly the information into the pixel of the original image. The first techniques embedded the bit message in a sequential way in the LSB (Low Significant Bit) of the pixel image [9, 10]. They have been improved by using a PRNG (Pseudo-Random Number Generator) and a secret key in order to have private access to the embedded information. The PRNG spreads over the image the message and makes hard the steganalyses [11]. Although those spatial hiding methods are not robust against attacks, they enable to embed a great amount of information.

For this paper, we have used an algorithm to embed the color palette information in the LSB of the *index* image of N pixels. The objective is thus to embed a message W made up of l bits b_j ($W = b_1 b_2 ... b_l$). The embedding factor, in $bit/pixel$, is $E_f = l/N$. The *index* image is then divided in areas of size $\lfloor 1/E_f \rfloor$ pixels. Each area is used to hide only one bit b_j of the message. This splitting procedure guarantees that the message is spread homogeneously over the whole *index* image. In order to hide the color palette in the *index* image we need to embed $l = 3 \times 256 \times 8 = 6144$ bits (the number of colors is $K = 256$).

Consequently, the embedding factor E_f, only depends on the *index* image size N. In our process, the PRNG selects randomly, for each region, a pixel $Index(i)$. In order to get a marked pixel $Index_W(i)$, the LSB of this selected pixel $Index(i)$ is then modified according to the message bit b_j[2]:

$$Index_W(i) = Index(i) - Index(i)\ mod\ 2 + b_j.$$

[1] m is set to 2 for computational complexity reduction.

[2] The formula is given for *index* values belonging to [0,K-1].

This way to embed the color palette ensure that each marked pixel is at worst modified by one grey-level and in the same time that the rebuilt color pixel would not be very far from the right color value. Indeed, the third term of Equation 1 ensures that consecutive couples of color are close.

4. RESULTS

We have applied our method on well known color images of size 256×256 pixels. For all the experiments, $\lambda_1 = 1$, $\lambda_2 = 0.01 \times N/(K+1)$ and $m = 2$ (see Equation 1). The results obtained show that the approach is efficient whatever the image type. In Figure 1, the main steps of our approach are comment for the baboon image.

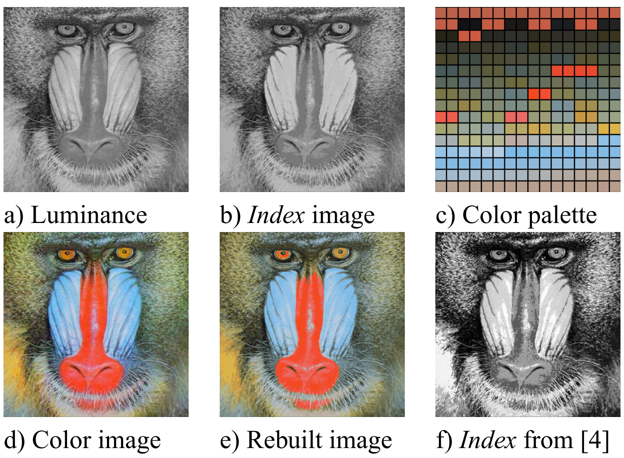

Fig. 1. Steps of the color secured.

After proceeding to the minimization of Equation 1 on the baboon image with $K = 256$ colors we obtain an *index* image in Figure 1.b and its color palette in Figure 1.c. The luminance image of the original color image is given in Figure 1.a. One could observe the good similarity between *index* image and luminance image. The good PSNR value of 27.90 dB confirms this subjective feeling. In comparison to the *index* image obtained in [4] and given in Figure 1.f (PSNR = 16.32 dB) the proposed approach is really better to obtain a visually pleasant *index* image. The first step of the method proposed in [4] was a quantization on K=256 colors which implies a quite flat histogram (see *Index* histogram with k-mean in Figure 2) and then a week similarity with the luminance histogram. In our proposed method, the grey-level range and the histogram shape of the *index* image (Figure 2) are nearer from the luminance histogram. One could also observe on the *index* histogram of Figure 2 that lots of *index* color are unused which explain the presence of some useless colors on the color palette of Figure 1.c. Also note that in the color palette in Figure 1.c, consecutive couples of color are colorimetricly close as expressed by the third term of Equation 1.

The length of our embedded message (color palette) is

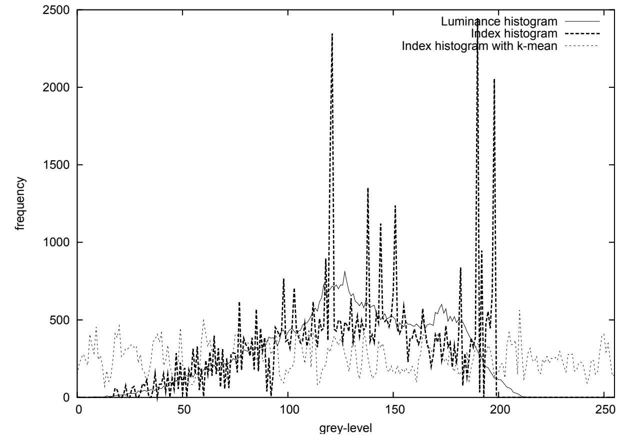

Fig. 2. Histograms.

$l = 6144$ bits which gives an embedding factor for an image of 256×256 pixels of $E_f = 6144/(256 \times 256) = 0.093$ bits/pixels. The *index* image is then cut in block of 10 pixels. In each 10-pixel block, a bit of the color palette is embedded at the position selected by the PRNG as explain in Section 3. The secured is obtain through the used of a secret key of 128 bits as a seed for the PRNG. The distribution of the message over the image is then key-related.

Figure 1.e shows the rebuilt color image from the *index*-marked one. This image is not visually far from the original color image even if the PSNR value of 27.90 dB is of middle quality. Note that the degradation due to the data-hiding method is weak because it disturb *index* values of a maximum of one. This is made possible thanks to the color palette property to own consecutive couples of close colors.

Few PSNR values are given on the Table 1. Rebuilt color images are of midle quality (over 27 dB) but visually pleasant. PSNR values for *index*-marked images are over 29 dB which is a really good result in comparison to the results of [4].

Table 1. PSNR comparisons

images	$\text{PSNR}^{luminance}_{(original,index-marked)}$	$\text{PSNR}^{color}_{(original,rebuilt)}$
baboon	29.74 dB	27.90 dB
airplane	35.95 dB	33.66 dB
pepper	35.03 dB	31.68 dB
house	35.40 dB	35.45 dB
barbara	34.86 dB	30.74 dB

5. CONCLUSION

In this paper, we have proposed a method to embed securely into a grey level image its color information. This method is built on a decomposition of a color image in a *index* image and a color palette. The *index* image is playing the role of the luminance image and the color palette is hidden into this *index* image. The method is made of two main steps which are the color image decomposition (into an *index* image and a color palette) and the data hiding. The originality of this paper is to model the problem with an energetic function and then minimize it. Obtained results show a real improvement in comparison to [4]. Our perspective work will treat of compression possibilities and other more robust data-hiding approaches.

APPENDIX

$P_{i,k}$ computation

Knowing that the membership values should belong to the range [0, 1] and that $\forall i \sum_{k=1}^{K} P_{i,k} = 1$ we are expressing this supplementary constraint by re-writing Equation 1:

$$E_{mod} = E + \lambda \sum_{i=1}^{N} \sum_{k=1}^{K} (1 - P_{i,k})$$

By cancelling $\frac{\partial E_{mod}}{\partial P_{i,k}}$ we are able to expressed $P_{i,k}$:

$$P_{i,k} = \frac{\lambda}{2 \times ((C(k) - I(i))^2 + \lambda_1 (Y(i) - k)^2)} \quad (5)$$

λ is deduced from the fact that $\forall i \sum_{k=1}^{K} P_{i,k} = 1$:

$$\lambda = \frac{1}{\sum_{l=1}^{K} \frac{1}{2 \times ((C(l) - I(i))^2 + \lambda_1 (Y(i) - l)^2}}$$

Equation 4 is then obtain by substitute λ in Equation 5.

C(k) computation

By cancelling $\frac{\partial E}{\partial C(k)}$ we are able to expressed $C(k)$ with a linear system given in Equation 3; Matrix of that system A.C = B are given below:

$$A = \begin{pmatrix} \lambda_2 + \sum_{i=1}^{i=N} P_{i,1}^m & -\lambda_2 & 0 & \dots \\ -\lambda_2 & \lambda_2 + \sum_{i=1}^{i=N} P_{i,2}^m & 0 & \dots \\ 0 & 0 & \lambda_2 + \sum_{i=1}^{i=N} P_{i,3}^m & \dots \\ 0 & 0 & -\lambda_2 & \dots \\ \dots & \dots & \dots & \dots \end{pmatrix}$$

$$B = \begin{pmatrix} \sum_{i=1}^{i=N} P_{i,1}^m I(i) \\ \sum_{i=1}^{i=N} P_{i,2}^m I(i) \\ \dots \\ \sum_{i=1}^{i=N} P_{i,K-1}^m I(i) \\ \sum_{i=1}^{i=N} P_{i,K}^m I(i) \end{pmatrix}$$

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