Watermarking of Color Images based on a multi-layer process

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Introduction

In this paper we present a new method of watermarking devoted to color images. Watermarking technics generally sign images by introducing changes that are imperceptible to the human eye, but are easily recoverable by a computer program. The locations in the image where the signature is embedded are determined by a secret key in order to prevent possible attacks by pirates or alterations due to compression and coding transformations, or geometrical transformations.

Meanwhile a lot of methods have been proposed to watermark grey level images, only few methods have been devoted to color images. In [1], Kutter proposed a new method to watermark a color image based on amplitude modulation of the blue channel, depending on the value of the bit, and proportional to the luminance. Next, Kim et al. proposed in [2] an another method based on magnitude increase of the saturation component with the contrainst that the resulting color difference is acceptable to the human visual system (HVS). Likewise, Fleet and Heeger proposed in [3] to use a human color vision model to control the amplitude of color degradations in order to ensure the invisibility of the embedded signal. More recently, Colduc and al. proposed in [4] an histogram embedding strategy based on a region selection approach to watermark the luminance component. Lastly, Vidal et al. proposed in [5], and Campisi and al. proposed in [6], an another kind of strategy which consists to watermark the image in the frequency domain.

The main limit of these methods is that they embed only one data feature. Thus, in [1] Kutter embeds the blue component into the spatial domain, in [2] Kim embeds the saturation component into the spatial domain, and in [3] Fleet embeds the yellow-blue component into the frequency domain.

Rather than embedding only one data feature, we propose a new strategy which consists to embed :

- the luminance (Y) channel at many different pixel locations in the spatial domain relatively to luminance values,
- the saturation (S) component of the ($CrCb$) chromatic plane at many different pixel locations in the spatial domain relatively to the saturation values,
- the luminance (Y) channel at many different pixel locations in the spatial domain relatively to chromatic edge values,
- the color ($YCrCb$) components at many different pixel locations in the spatial domain relatively to the Contrast Sensitivity Function (CSF),
- the luminance histogram (H^Y) of each regions in the spatial domain relatively to regional emergence of regions,
- the saturation (S) component of each regions in the spatial domain relatively to their hue.

The basic idea of this strategy is to put different watermarks into the image in many different locations with the contrainst that a pixel can not be watermarked twice except if color components watermarked are differents. For example the luminance and the saturation of a pixel can be both watermarked according two different strategies as these two color components are not correlated. Different processes, based on the methods previously cited, are used to put a watermark into the image in different locations. These locations corresponds either to pixel positions or regions.

The second idea of this paper is to take into account the properties of the human visual system to perceive both simultaneously and separately (see [7]), ponctual and regional color images differences [8–10]. These properties are used to select the less salient parts of the image to watermark, and to control the strength of each watermark process.

The new method proposed consists of using a multi-layer process of insertion which enables to insert various watermark signals in the spatial domain proportionnally to the contents of the image and to the sensitivity to the Human Visual System to perceive color differences. Watermark signals are embedded from an additive scheme so that they can be detected (decoded) without use of the original image.

Watermark signals embedded into the original image have been defined to obtain a trade-off between robustness and invisibility. The more the power of the watermark signals increases, the more image degradations are perceiptive to the human visual system and easier to decode. To ensure that the embedded signals are invisible, i.e. to control that they are below a certain threshold, we have used a quantitative model of human visual discriminability. In order to assess color differences between the original image and the watermarked image, we have considered the $YCrCb$ color space. We have choosen this color space for several reasons. First because, as in the human visual system, the $YCrCb$ color space enables to dissociate the luminance component Y from the chrominance components $CrCb$. Moreover, the luminance component Y is proportionnal to visual perception luminance using the Weber-Fechner's Law, and the chrominance components $CrCb$ is proportionnal to the Constrat Sensitivity Function (CSF). Secondly, because the $YCrCb$ color space is the color space used in the JPEG image compression standard and in the MPEG video compression standard [11].

Steps of the watermarking process

The multi-layer process proposed to watermark color image is based on six color watermarking steps.

Step 1 : Watermark of the luminance (Y) channel

Considering that the human eye is less sensitive to luminance changes in high luminance values and less luminance values, a signature is embedded in the luminance (Y) channel on pixels having a luminance value lesser than Y_{thr1} and higher than Y_{thr2}.

A multiple bit embedding strategy is used to watermark the image (see [1]), it consists to modify pixel values in the luminance channel. These modifications are either additives or substractives, depending of the value of the bit, and proportionnals to the luminance. Thus :

$$Y(i,j) = Y(i,j) \; + \; q_1(2b-1)Y(i,j) \qquad (1)$$

where q_1 is a constant determining the signature strength. The value q_1 is selected such as to offer best trade-off between robustness and invisibility. (i,j) is a location within the image defined by a pseudo-random process, it depends of a secret key $K1$. b is the single bit to be embedded in the image.

Step 2 : Watermark of the saturation (S) component

Considering that the human eye is less sensitive to saturation changes than to hue changes, a signature is embedded in the saturation (S) component on pixels having a saturation value higher than S_{thr1}, and having a luminance value higher than Y_{thr1} and lesser than Y_{thr2}.

Considering that the phase of a point in the $CrCb$ plane from the Cr axis represents the hue H property, and that the magnitude of the point from origin of the $CrCb$ plane represents the saturation S property (see figure 1), a magnitude embedding strategy is used to watermark the image [2]. This strategy consists to increase the saturation of pixel value in order to obtain purer color (see figure 1).

These modifications are only additives, and proportionnals to the saturation. Thus :

$$S(i,j) = S(i,j) \; + \; q_2 \, (S_{max} - S(i,j)) \qquad (2)$$

where S_{max} is the maximum realizable saturation for a color, S_{max} depends of the hue and of the luminance [12]. q_2 is a constant determining the signature strength. The value q_2 is selected such as to offer best trade-off between robustness and invisibility. (i,j) is a location within the image defined by a pseudo-random process, it depends of a secret key $K2$.

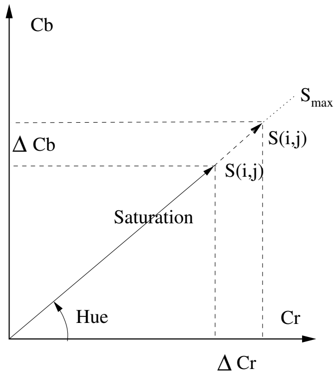

Figure 1: Embedding of the saturation component into the original $CrCb$ chrominance components.

Step 3 : Watermark of the edge (E) component

Considering that the human eye is less sensitive to achromatic edges than to chromatic edges, a signature is embedded in the luminance (Y) channel on edge pixels having an edge value higher than E_{thr1} on the Y luminance component, and an edge value lesser than E_{thr2} on the $CrCb$ chrominance plane. Achromatic and chromatic edges are computed according to the color gradient strategy proposed by Di Zenzo [13, 14].

A contrast embedding strategy is used to watermark the image, it consists to modify pixel values in the luminance channel. These modifications are either additives or substractives, depending of the value of the edge on the $CrCb$ chrominance plane, and proportionnals to the luminance. Thus :

$$Y(i,j) = Y(i,j) \; + \; q_3 \; E_{CrCb}(i,j) \qquad (3)$$

where $E_{CrCb}(i,j)$ is the edge value at pixel location (i,j) computed in the $CrCb$ chrominance plane. q_3 is a constant determining the signature strength. The value q_3 is selected such as to offer best trade-off between robustness and invisibility. (i,j) is a location within the image defined by a pseudo-random process, it depends of a secret key $K3$.

Step 4 : Watermark of the spatial frequency (S_aF) component

Considering that the human eye is less sensitive to changes in regions of high frequencies than changes in regions of low frequencies, a signature is embedded in the color (Y $CrCb$) components on pixels having a frequency value higher than f_{thr1}.

A spatial frequency embedding strategy is used to watermark the image, it consists to modify pixel values in all color components. These modifications depend of the value of the spatial frequency of each color component, and are proportionnals to the values of these color components.

The spatial frequency response of a color image can be modeled approximately by :

$$SF(\omega) = 1.5 \exp^{-\sigma^2\omega^2/2} - \exp^{-2\sigma^2\omega^2} \quad (4)$$

where $$\sigma = 2, \quad \omega = \frac{2\pi f}{60}, \quad f = \sqrt{u^2+v^2} \quad (5)$$

and u and v are the horizontal and vertical frequencies, respectively, in cycles per degree.

This equation is based on a Contrast Sensitivity Function (CSF) [7, 15].

At higher spatial frequencies, the frequency response is anisotropic so that a better model is given by [7] :

$$SF_a(u,v) = SF(\omega)\ O(\omega,\theta) \quad (6)$$

with $$O(\omega,\theta) = \frac{1+\exp^{\beta(\omega-\omega_0)}\cos^4 2\theta}{1+\exp^{\beta(\omega-\omega_0)}} \quad (7)$$

where $\theta = \tan^{-1}(v/u)$ is the angle with respect to the horizontal axis,

$$\beta = 8, \quad f_0 = 11.13\ cycle/degree \quad (8)$$

and $O(\omega,\theta)$ blends in a $\cos^4 2\theta$ anisotropy, fairly quickly, for frequencies $f > f_0$.

Let us note $Y_f(i,j)$ the frequency weighted luminance defined by :

$$Y_{SF}(i,j) = q_4\ Y(i,j) * SF_a^Y(i,j) \quad (9)$$

$Y_{SF}(i,j)$ represents the luminance $Y(i,j)$ component filtered with $SF_a^Y(u,v)$.

Likewise, $Cr_{SF}(i,j)$ and $Cb_{SF}(i,j)$ represent the chrominance components filtered with $SF_a^{Cr}(u,v)$ and $SF_a^{Cb}(u,v)$, respectively, according to f_0^{Cr} and f_0^{Cb} threshold values.

q_4 is a constant determining the signature strength. The value q_4 is selected such as to offer best trade-off between robustness and invisibility. (i,j) is a location within the image defined by a pseudo-random process, it depends of a secret key $K4$.

Step 5 : Watermark of the histogram (H) of the luminance channel

Considering that the human eye is less sensitive to some color changes in regions than to some color changes in pixels, a signature is embedded into each region of the image.

An histogram embedding strategy, based on a region selection approach, is used to watermark the image [4], it consists to modify histogram values of the luminance channel. These modifications are either additives or substractives, depending of the values already modified in order to preserve original histogram. This basic idea of the proposed strategy consists to annulate the bins of some notches positions by eliminating certain graylevels intervals from region graylevel histogram. The number of notches k, the location of the center, and the width $2d+1$ are defined such as to offer best trade-off between robustness and invisibility.

First, the image is splitted into two regions R_1 and R_2, such as R_1 and R_2 recover the entire image, next each region is separately marked. Regions R_1 and R_2 are defined according to a secret process, which first coarsely segments the image in regions using a region growing process, and next merges adjacent regions using a measure of similarity based on regional emergence of regions [16].

Let $H_1 = \{h_1(1), h_1(2), \dots\}$ and $H_2 = \{h_2(1), h_2(2), \dots\}$ be the luminance histograms of each specified regions. Let $W^1 = \{w_1^1, w_2^1, \dots w_k^1\}$ and $W^2 = \{w_1^2, w_2^2, \dots w_k^2\}$, where the subscript denotes the graylevel of the center of the corresponding notch, be the watermarks to be inserted in the histograms H_1 and H_2, respectively. W^1 and W^2 are defined by a secret key $K5$.

Histograms are modified as follows. Around each w_i^1, bins of H_1 are added to the corresponding positions of H_2, such as :

$$h_2(w_j^1+p) = h_2(w_j^1+p) + h_1(w_j^1+p) \quad (10)$$

where $j = 1, \dots, k$ and $p = -d, \dots, d$. Furthemore, notches are created in H_1, such as :

$$h_1(w_j^1+p) = 0 \quad (11)$$

where $j = 1, \dots, k$ and $p = -d, \dots, d$.

Similarly, the same transform is done for H_2 by :

$$h_1(w_j^2+p) = h_1(w_j^2+p) + h_2(w_j^2+p) \quad (12)$$

where $j = 1, \dots, k$ and $p = -d, \dots, d$. Furthemore, notches are created in H_2 such as :

$$h_2(w_j^2+p) = 0 \quad (13)$$

where $j = 1, \dots, k$ and $p = -d, \dots, d$.

Let H_1^* and H_2^* be the histogram transformed by these equations. By construction, we have necessarily :

$$H_1^* + H_2^* = H_1 + H_2 \quad (14)$$

Step 6 : Watermark of the saturation (S) component

Considering that the human eye is less sensitive to saturation changes in some color regions than saturation changes in other color regions, a signature is embedded into each color regions having a certain hue belonging to a given set of gamuts H_{set1}, and having a size lesser than $Size_{thr1}$.

First, the image is splitted into two regions R_3 and R_4, such as R_3 and R_4 recover the entire image, next each region is separately marked. Regions R_3 and R_4 are defined according to a secret process, which first coarsely segments the image in regions using a k-means quantization process, and next gather all regions having a hue nearer to the set of gamuts H_{set1} to region R_3 and others to region R_4.

Then, a magnitude embedding strategy is used to watermark the image (see step 2). This strategy consists to increase the saturation of pixel belonging to region R_3 in order to obtain purer color, and to decrease proportionnaly the saturation of pixel belonging to region R_4.

Meanwhile these modifications are additives to pixels belonging to region R_3, these modifications are substractives to pixels belonging to region R_4. In two cases, these modifications are proportionnals to the saturation. Thus :

$$S(i,j) = S(i,j) \; + \; q_6 \; (S_{max} - S(i,j)) \;\; if \; (i,j) \in R_3 \quad (15)$$

where S_{max} is the maximum realizable saturation for a color, S_{max} depends of the hue and of the luminance [12]. q_6 is a constant determining the signature strength. The value q_6 is selected such as to offer best trade-off between robustness and invisibility.

$$S(i,j) = S(i,j) \; - \; q'_6 \; (S_{max} - S(i,j)) \;\; if \; (i,j) \in R_4 \quad (16)$$

where q'_6 is defined such as :

$$\sum_{(i,j)\in R_4} q'_6 \; (S_{max} - S(i,j)) = \sum_{(i,j)\in R_3} q_6 \; (S_{max} - S(i,j)) \quad (17)$$

The tradeoff between robustness and invisibility

According to differents studies, we can consider that if a color difference ΔE_{CrCb} is lesser than 3 then this difference is none noticeable to the observer [2]. On the other hand, if a color color difference ΔE_{CrCb} is bigger than 3, but lesser than 6, then this difference is perceptible to the human visual system, but nevertheless acceptable. If the color difference ΔE_{CrCb} is bigger than 6 then this difference is visible, and the two colors involved are considered as differents colors. We have used the same thresholds to analyse, from the Mean Squared Error measure (MSE), the degree of visibility of our watermark process, and to adjust independently each parameters q_1, q_2, q_3, q_4, q_5, and q_6.

Through an iterative process, we have progressively amplified the amplitude of additive and subtractive modifications corresponding to each proposed transform $T_i, i = 1, \ldots, 6$ (see step 1 to step 6 of the process), in increasing the value of q_i with an increment of 2% (the q_i value is initially fixed to 2%) until having a MSE measure bigger than 6. The interest of such an iterative process is that it enables to adjust automatically the value of each parameters of the watermark process, this in order to obtain a good tradeoff between robustness and invisibility.

Perspectives

The next step of our work will consist to study the robustness of the secret procedure used. We will study if the transformed images can be easily detected from any image attack process.

We will analyse also how to recover the embedded watermark signal from an image in using inverse, but not symmetric, functions of the embedding functions.

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