Digital Watermarking Based on Color Differences

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ABSTRACT

In this paper, we proposed the digital watermarking for a color image. In order to embed watermark signal, we consider the characteristics of HVS(human visual system) and focus on the relatively insensitive components of a color image. In YCrCb color space, Y component is achromatic - luminance and both Cr and Cb components are chromatic - color. At the Cr-Cb chrominance plane, an angle of a pixel represents the hue component of a color that refers to its average spectral wavelength and differentiates different colors and a magnitude of a pixel determines the amount of purity of the color. Because the variation of saturation is less sensitive than that of hue, we modify the saturation value – the magnitude in Cr-Cb chrominance plane. On changing the chrominance data, the phase of a point has to be fixed and only the magnitude of the point that represents the saturation is changed based on the acceptable degree of color difference. The proposed digital watermarking method has a good property in the field of invisibility.

Keywords: digital watermarking, contrast sensitivity function, achromatic and chromatic components, color difference

1. INTRODUCTION

Recently, due to the rapid expansion of the internet, various kinds of digital media have increasingly been treated and transferred by many users all over the world, for example, still pictures, video, music, text and programs. The use of digital media for image and video sequences has some serious implications for copyright protection issues[1,2].

In the early days, without access to negatives, it was relatively difficult to pirate images as it was necessary to use expensive scanners that were not widely available. However, scanners are virtually omnipresent recently and, once the image is in the digital environment, very low cost but high quality processing software can be used to manipulate the image in ways that would have been impossible only a few years ago. Video is still slightly more difficult as a capture card and large amounts of disk space are required – but even this is not onerous nowadays.

Copyright of digital contents such as digital images has been invaded since they can be easily copied without degradation of quality. Thus it is urgently required to protect copyright from illegal usage. One of the techniques to protect copyright of digital contents is embedding watermarks into digital contents and several watermarking methods have been proposed. A watermarking method not only checks unjust usage but also protects unjust usage in advance by existence of itself and raises consciousness of protecting copyright.

In general, watermarks are classified into two categories: visible[3] and invisible[2] watermarking. The watermark of visible watermarking which is visible when viewing the watermarked image, exists to warn pirates against illegal copying or collision. The main disadvantage of visible watermarking is that they destroy the image quality and are easily attacked through direct image processing. In contrast, invisible watermarking is imperceptible to those viewing the image, and the watermark is still present in the multimedia data even after various signal processing or transmission distortions. The watermark by invisible watermarking techniques is extracted from the watermarked image to show ownership.

The techniques of protecting copyright of digital contents have not been applied enough for the sake of technical problems of embedding watermark into digital contents and of authenticating copyright information extracted from the digital contents. The requirements of a watermarking scheme for copyright protection purposes are as follows:

(1) The image should not be visibly degraded by the presence of the mark while a unique identifier with high information content is produced simultaneously.
(2) The mark must be readily recoverable by the comparison with the original image.

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(3) The mark must be strongly resistant to detection and decoding without access to the original. It must be strongly resistant to attack and it should cause a significant loss of image quality for it to be destroyed. In addition, the mark must be tolerant to reasonable quality lossy compression of the image.

Some recent papers have considered data hiding in color images. Kutter[4] proposes an amplitude modulation scheme where in signature bits are multiply embedded by modifying pixel values in the blue channel. The blue channel is chosen as the human visual system is less sensitive to blue than other primary colors. Also, changes in regions of high frequencies and high luminance are less perceptible, and thus are favorable locations for data embedding. Robustness is achieved by embedding the signature several times at many different locations in the image. Fleet *et al.* [5] propose an embedding scheme using the S-CIELAB, a well-known standard for measuring color reproduction errors. They embed amplitude-modulated sinusoidal signals into the yellow-blue color band of an opponent color representation scheme.

At first, we consider the characteristics of the human visual system in order to embedding watermark signal in this paper. In general, achromatic component – luminance that in low frequency region is more sensitive than chromatic components – colors that in middle one. Thus we focus on the relatively insensitive components of a color image.

In the next section, we present the basic concept of color. In section 3, we introduce the proposed digital watermarking that contains embedding and extracting procedure. Then experimental results and some remarks are shown in section 4. Conclusions are provided in section 5.

2. BACKGROUND

2.1. Contrast Sensitivity Functions (CSFs)

In this paper, CSF is a model that approximates the response of the human visual system. There are several things to notice about the CSFs. The first is that the spatial frequency response of the achromatic component has the characteristics of a band-pass filter. Contrast sensitivity is highest for gratings with frequencies around 2 to 4 cycles/degree(*cpd)* of visual angle.

On the other hand, the spatial frequency response of the chromatic components has the characteristic of a low-pass filter. Sensitivity is good for low spatial frequencies, but declines at higher frequencies.

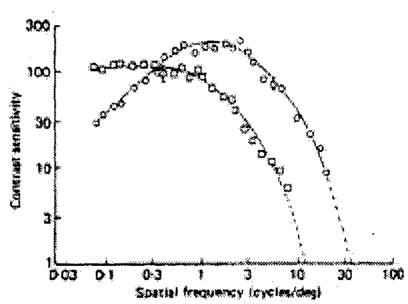

Figure 1. Contrast sensitivity as a function of spatial frequency for achromatic(o) and chromatic(□)[6].

The high frequency cutoffs of the CSF's indicate the limits of spatial resolution in the two – achromatic and chromatic components in Figure 1. The achromatic component has a cutoff at approximately 30 *cpd* which is in good correspondence with the limits of visual acuity measured in clinical tests. The high frequency cutoff for the chromatic components is only 11*cpd.* Therefore, the chromatic components have much lower spatial resolution than the achromatic component.

2.2. Color Space

A color space is a mathematical representation of a set of colors. Three fundamental color models are RGB used in color computer graphics and color television, YIQ, YUV or YCrCb used in broadcast and television systems, and CMYK used in color printing[7]. However, none of these color spaces are directly related to the intuitive notions of hue, saturation, and brightness. This problem causes the development of other models, such as HIS and HSV, to simplify programming, processing, and end-user manipulation.

2.2.1. RGB

The red, green, and blue (RGB) color space is widely used throughout computer graphics and imaging. Red, green, and blue are three primary additive colors which the individual components are added together to form a desired color and are represented by a three-dimensional, Cartesian coordinate system in Figure 2.

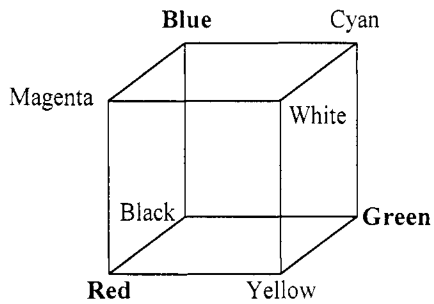

Figure 2. RGB color cube system.

However, RGB is not very efficient when dealing with "real-world" images. All three RGB components need to be of equal bandwidth to generate any color within the RGB color cube. The result of this is a frame buffer that has the same pixel depth and display resolution for each RGB component. Also processing an image in the RGB color space is not the most efficient method. To modify color of a given pixel, we need the calculation of converting from RGB to a color space that contains the intensity and color components such as hue and saturation. For these reasons, many video, and image standards use achromatic and chromatic signals.

2.2.2. YCrCb

In this paper, we consider YCrCb color space which was developed as part of Recommendation CCIR601 and are scaled and offset versions of the YUV color space. Y is defined to have a nominal range of 16 to 235; Cr and Cb are defined to have a range of 16 to 240, with 128 equal to zero. There are several YCrCb sampling formats, such as 4:4:4, 4:2:2, and 4:1:1.

If the gamma-corrected RGB data has a range of 0 to 255, as is commonly found in computer systems, the following equations may be more convenient to use. For the YCrCb-to-RGB equations, the RGB values must be saturated at the 0 and 255 levels sue to occasional excursions outside the nominal YCrCb ranges.

RGB to YCrCb Conversion

$$\begin{aligned} Y &= 0.257R'+0.504G'+0.098B'+16 \\ Cr &= 0.439R'-0.368G'-0.071B'+128 \\ Cb &= -0.148R'-0.291G'+0.439B'+128 \end{aligned} \quad (1)$$

YCrCb to RGB Conversion

$$\begin{aligned} R' &= 1.164(Y-16)+1.596(Cr-128) \\ G' &= 1.164(Y-16)-0.813(Cr-128)-0.391(Cb-128) \\ B' &= 1.164(Y-16)+2.018(Cb-128) \end{aligned} \quad (2)$$

2.2.3. Cr-Cb chrominance plane

Figure 3 shows the three basis color(Red, Green, Blue) representation in the Cr-Cb chrominance plane.

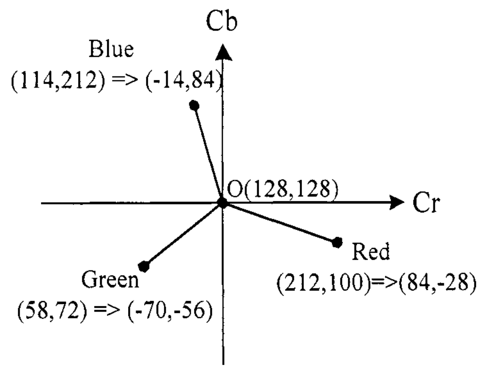

Figure 3. Cr-Cb chrominance plane

2.3. Color Difference

The color difference in YCrCb color space is defined below

$$\Delta E^{*}_{CrCb} = \left[\left(\Delta Y^{*}\right)^{2} + \left(\Delta Cr^{*}\right)^{2} + \left(\Delta Cb^{*}\right)^{2} \right]^{1/2}. \tag{3}$$

There exists inevitable color difference between the original and its reproduction due to inherent limitations such as gamut mapping mismatch and difference in dynamic range of their reproducible colors. According to Hardeberg[8], if the color difference is less than 3, HVS(human visual system) can not discriminate the difference and if the color difference is bigger than 3 and less than 6, two colors are classified approximately as same colors though the difference can be perceived and if the color difference is bigger than 6, two colors are recognized as different colors. We can measure the Cr-Cb color difference level using Eq.(3) in YCrCb color space and Table 1 shows the acceptable degree of color difference.

Table 1. Acceptable degree of color difference

ΔE_{CrCb}	Visual Effect
$\Delta E_{CrCb} < 3$	Not perceptible
$3 \le \Delta E_{CrCb} < 6$	Perceptible but acceptable
$\Delta E_{CrCb} \ge 6$	Not acceptable

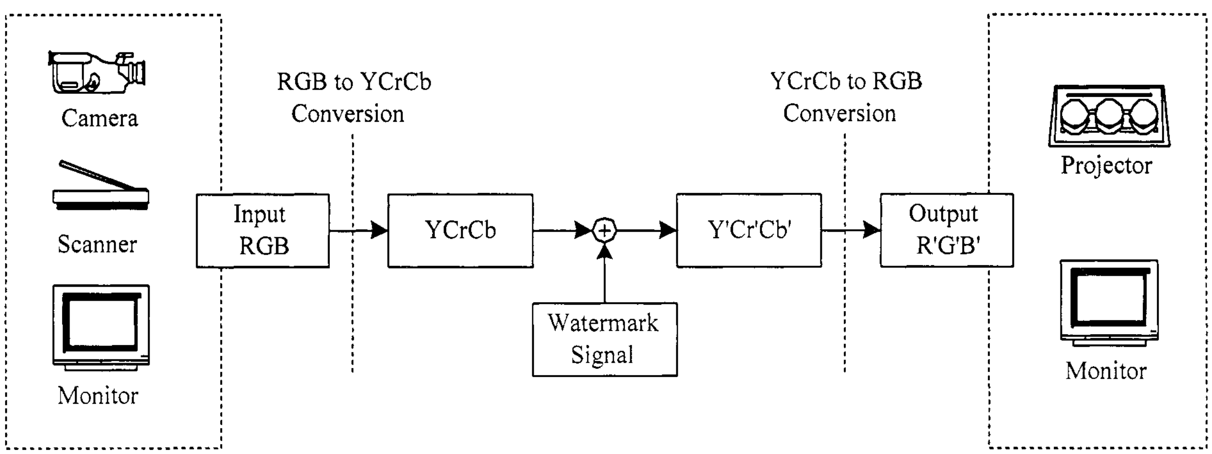

Figure 4. Proposed watermarking scheme.

3. PROPOSED METHOD

Based on chromatic components (Cr, Cb) are less sensitive than achromatic one (Y), we insert the watermark signal into chromatic region. At the Cr-Cb chrominance plane, an angle of a pixel represents the hue component of a color that refers to its average spectral wavelength and differentiates different colors and a magnitude of a pixel determines the amount of purity of the color. Because the variation of saturation is less sensitive than that of hue between chromatic components - hue and saturation, we manipulate the saturation value to embed the watermark signal according to acceptable degree of color difference.

3.1. Watermark Embedding

In YCrCb color space, Y is achromatic component, luminance that summed up each different rates red, green, and blue of a pixel and Cr and Cb are chromatic components, color. Then we use the Cr-Cb chrominance plane to embed watermark signal. The *phase* of a point in the Cr-Cb plane from the Cr axis differentiates different colors, representing the *hue* property. On the other hand, the *magnitude* of the point from origin of the Cr-Cb plane has the *saturation* property. As the *magnitude* from the origin increases, we will have purer colors.

$$Phase = tan^{-1}\frac{Cb}{Cr} \tag{3}$$

$$Magnitude = \sqrt{Cr^2 + Cb^2} \tag{4}$$

Then watermark signal is embedded into the original Cr-Cb chrominance components. To modify the less sensitive color components, we separate both luminance and colors of YCrCb color space from the RGB color space. A schematic of the embedding procedure is shown in Figure 5. On changing the chrominance data, the phase of a point has to be fixed and only the magnitude of the point that represents the saturation is changed based on the acceptable degree of color difference[4].

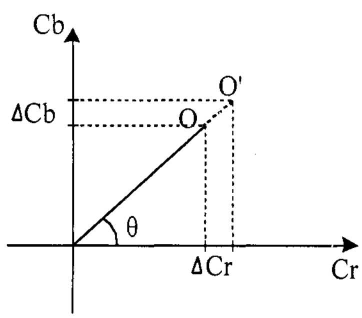

Figure 5. Embedding method in Cr-Cb chrominance plane.

3.2. Watermark Extraction

In watermark signal recovery, at first the watermarked image and original image are converted into the same YCrCb color space and then comparison procedure between two magnitudes is executed. In further studies, the extracting procedure without the original image is considered.

4. EXPERIMENTS

Before the experiment of digital watermarking, we examine whether the color space conversion of RGB to YCrCb, and YCrCb to RGB effects in image quality or not. Its results show that the color space conversion doesn't make the degradation of image quality. In experiment, we used the 256 x 256 'LENA' image and the same size of watermark signal.

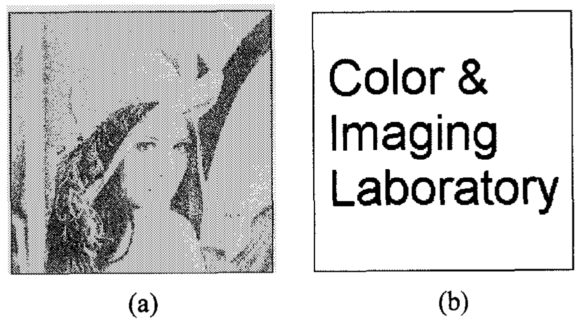

Figure 6. Experimental images. (a) original image, (b) watermark signal

The simulation results indicate that the proposed watermarking method has good properties in the field of invisibility in Figure 7. The extracted watermark in Figure 7(b) has several defects in the bright region of the test image. To solve this defect, we must consider the characteristics of HVS in luminance. Amount of the embedded the watermark is decided directly proportional to the brightness of an image.

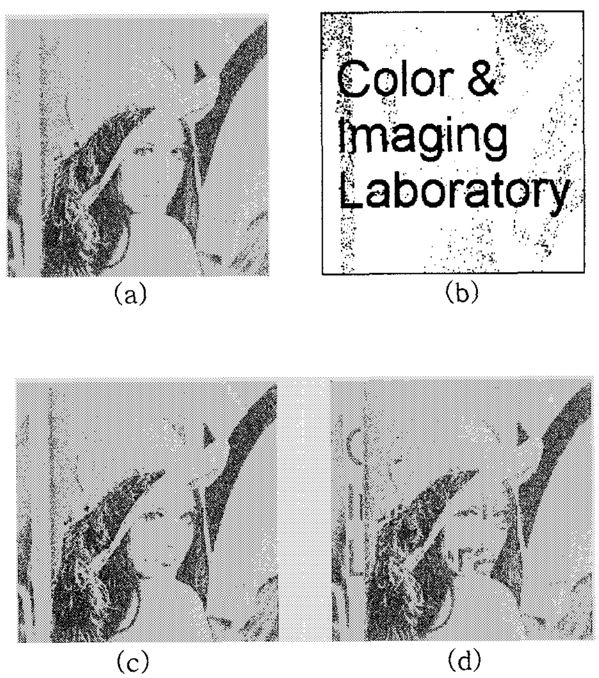

Figure 7. Experimental Results related on the acceptable degree of color difference.
(a) Watermarked image within 3% color difference, (b) extracted watermark image from (a), (c) watermarked image with 30%, and (d) watermarked image with 50%

To compare the similarity between original and watermark embedded image, we define the Eq.(5). The PSNR for RGB color image is calculated by

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{5}$$

$$where \quad MSE = \frac{1}{3nm}\cdot\frac{1}{n}\cdot\frac{1}{m}\sum_{R,G,B}\sum_{n}\sum_{m}\left(E_{org} - E_{emb}\right)^2$$

where E_{org} and E_{emb} respectively denote the brightness levels of an original image and a watermark embedded image.

Table 2. PSNR comparison related on the acceptable degree of color difference [dB]

	No inserting (0%)	1%	2%	3%	10%	30%	50%
Red	Infinite	13.45	10.63	10.42	10.47	10.85	11.25
Green	Infinite	Infinite	61.20	59.25	50.05	40.58	35.89
Blue	Infinite	48.14	21.05	17.87	16.16	16.01	16.07

5. CONCLUSIONS

In this paper, we proposed the digital watermarking suitable for a color image. In order to embed watermark signal, we consider the characteristics of HVS and focus on the relatively insensitive components of a color image. Because the variation of saturation is less sensitive than that of hue, we modify the saturation value – the magnitude in Cr-Cb chrominance plane. On changing the chrominance data, the phase of a point has to be fixed and only the magnitude of the point that represents the saturation is changed based on the acceptable degree of color difference. The proposed digital watermarking method has a good property in the field of invisibility. However, It can be shown that the core problem with the attack described above lies with the compression operation of the watermark detection scheme. It follows that any digital watermarking scheme suitable for video applications does not need strongly original images, or video.

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