HVS-Based Imperceptibility Evaluation for Steganography

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Abstract. The aim of steganography is to conceal the very existence of hidden communication, so imperceptibility is the primary demand. However there are short of corresponding evaluation methods. Most researchers still use Peak-Signal-to-Noise Ratio (PSNR) for their imperceptibility evaluation, while ignoring the speciality of steganography. In this paper, firstly, we present an objective method of imperceptibility evaluation for gray image, which is based on both characteristics of steganography and human visual systems (HVS).Then, based on the color masking, metric CHPSNR for color image is proposed. CHPSNR relates embedding capacity to steganography, and can reflect the localized distortion of stego images. Extensive experimental results demonstrate that our method is superior to global PSNR, which is consistent with HVS and can effectively evaluate the performance of steganographic algorithm.

Keywords: steganography, HVS, evaluation, imperceptibility, Peak Signal to Noise Ratio.

1 Introduction

Information hiding has become the forefront of information security. As an intersecting subject, it includes mathematics, cryptography, information theory, computer vision and other computer application techniques. Information hiding has become the hot topic for researchers in the world [1-4]. There are many studies on steganography and steganalysis in published literatures. However, there are short of corresponding evaluation methods, which will hinder the development of information hiding [5, 6]. Therefore, it is urgent to establish a benchmark for information hiding.

Establishing a benchmark is to be considered based on performance indices including security, capacity, robustness and perception, etc. These indices are usually conflictive, but imperceptibility is the basic requirement. There are two methods to measure imperceptibility of steganography: (1) subjective evaluation: in designed experiments, some observers are chosen to rate the images by specified rules; (2) objective evaluation: some algorithms are used to evaluate the image degrades. Subjective evaluation is the same as the result judged by human vision, but it is time-consuming and complicated. Furthermore, it is influenced by some subjective factors such as observer's professional background, psychology and motivation. Objective evaluation

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has the advantage of convenience and quickness. It is easy to be realized in application systems, but inconsistent with HVS.

PSNR has been widely used as the important and even unique objective evaluation metric by many researchers up until now. But PSNR is unsuitable for evaluation because the nature of information hiding is not merely the relationship between signal and noise. To achieve the result perfectly matches with the quality perceived by human observers, HVS based objective evaluation has become the research emphasis.

In the next section, we introduce the HVS-based imperceptibility evaluation method. Section 3 describes a HVS-based evaluation method for gray image, on the basis of which a new evaluation metric CHPSNR for color stego image is proposed in section 4. Experimental results and conclusions are given in Section 5 and 6 respectively.

2 HVS-Based Imperceptibility Evaluation

HVS-based algorithms simulate some low-level characteristics of HVS, which map the absolute errors between cover images and stego images into JNDs(Just noticeable difference) that can be perceived by human vision. When errors are higher than sensitive threshold, they can be perceived, else be ignored. Through above processing, evaluation results consistent with observer's subjective perception can be achieved.

Details of HVS-based algorithm are as follows: (1) blocking: the image is divided into many regular blocks for the convenience of calculation;(2) the execution of decomposition: image blocks are decomposed by different spatial frequency and orientation, while every composition of spatial frequency and orientation called a channel; (3) comparison: compare cover images with stego images to acquire error images; (4) mask: apply temporal-spatial filter to every channel to simulate low-level characteristics of HVS, calculate errors on the background of reference images; (5) the execution of modeling: calculate and model the average errors of the whole images, relate them to mean opinion score (MOS) of image quality ,then estimate parameters of model on the testing sets[7,8]. This method simulates all the characteristics of HVS comprehensively, which can ensure the coherence of subjective evaluation and objective evaluation.

3 HPSNR Based on HVS for Gray Image

Human eyes process image with encoding the features extracted from spatial, frequency and color, not point-by-point. Human's Visual Perception Characteristics do not match with Statistical distribution of information. HVS sensitivity function in HVS model can be represented as:

$$H'(\omega) = (a + b\omega)\exp(-c\omega) \ . \tag{1}$$

where the radial frequency ω is in cycles per degree of visual angle subtended, a, b and c are constants that decide the shape of HVS. When $H'(\omega)$ arrives its peak around 3 cycles/degree, the shape of HVS is represented as

$$H'(\omega) = (0.2+0.45\omega)\exp(-0.18\omega) . \quad (2)$$

When applied DCT transform in image coding system, the original image is symmetrical extended. However, we can’t observe this scene that doesn’t exist at all. So the following correction function is employed [9]:

$$|A(\omega)| = \left\{ \frac{1}{4} + \frac{1}{\pi^2} \left[\log_e \left(\frac{2\pi\omega}{\alpha} + \sqrt{\frac{4\pi^2\omega^2}{\alpha^2} + 1} \right) \right]^2 \right\}^{\frac{1}{2}} . \quad (3)$$

where α =11.636/degree, hence, HVS sensitivity function can be calculated as:

$$H(\omega) = H'(\omega)|A(\omega)| = \begin{cases} 0.05\exp\left(\omega^{0.554}\right) & \omega < 7 \\ \exp[-9(|\log_{10}\omega - \log_{10} 9|^{2.3})] & \omega \ge 7 \end{cases} . \quad (4)$$

To convert from the two-dimensional (2-D) DCT variables i and j to ω, the following conversion formula is employed:

$$\omega(cycle/\deg ree) = \omega_d(cycle/pixel) * \omega_s(pixel/\deg ree) . \quad (5)$$

where $\omega_d = \frac{1}{2N}\sqrt{i^2 + j^2}$, $i, j = 0,1,......,N-1$, ω_s is the sampling density dependent upon the viewing distance, N is the DCT block size and is chosen to be eight. For a GIF image with a height of 288 pixels and viewed at a distance of four times the image height, ω_s is 20 pixels/degree. In our simulation, we chose ω_s to be the nearest number divisible by2N. i.e., ω_s =32.

Using HVS sensitivity function as weighted values, HPSNR is calculated as:

$$HPSNR = 10\log_{10}\frac{\max(x)^2}{\|H(\omega)(I'-I)\|^2} . \quad (6)$$

It is obvious that the bigger the HPSNR is, the better the quality of the image is.

For the convenience of comparing, we give the global PSNR for gray image:

$$PSNR = 10\log_{10}\left(\frac{\max(x)^2}{EMS}\right) . \quad (7)$$

where EMS is the mean square error of image under test.

An experiment is shown in figure 1.For a standard Lena image, we concentrate the noise on one of the copy, while on another copy we add gaussian noise evenly. Here we can distinguish the differences easily, however, they have the same PSNR. Obviously, PSNR is unsuitable for evaluating information hiding performance, but HPSNR matches with human vision perfectly.

(a) concentrated noise
PSNR=36.01db
HPSNR=79.84db

(b) scattered gaussian noise
PSNR=36.01db
HPSNR=80.88db

Fig. 1. HPSNR for images with the same PSNR

In another experiment, we use several typical steganography tools to hide different secret message into 1000 gray images which are select from USC-SIPI Image Database and digital camera. Table1 summarizes HPSNR results with some popular steganography tools.

Table 1. HPSNR for different steganography tools with various embedding capacity

Capacity	S3en	HIP	Ezstego	Stash It	Stools
2%	70.7921	68.9815	30.1018	29.9757	25.8865
5%	62.6225	60.3354	29.3230	29.2640	25.1502
10%	58.8701	56.9818	27.9846	28.2044	24.6170
20%	55.5026	53.9685	27.5806	27.1713	24.2023
30%	55.0575	53.2391	-----	-----	23.5823
40%	53.8178	51.1605	-----	-----	23.1587

From the table 1, we can find that S3en and Hide in Picture have the best imperceptibility, while Ezstego and Stash It are better than Stools, which matches with our direct observation. For S3en and Hide in Picture, modification for original image by LSB is least, therefore, they have the best imperceptibility; Stools is worse than Ezstego and Stash It which modify index value, because Stools reduces the color in color palette. We can draw the conclusion that HPSNR can be use to evaluate imperceptivity of gray image.

4 CHPSNR Based on HVS for Color Image

A color digital image is often represented by the color components(R, G, B). Due to three visual cells each of which is most sensitive to red light, green light and blue light, human have different color sensitivity. When external chromatic light stimulates our eyes, the mixture of different responses to these three cells forms color sensory. Human eyes' sensitivity to color is more complicated than luminance.

There are other color models such as YIQ model besides RGB model. The luminance component Y in YIQ model reflects comprehensive energy of color components (R,G,B),which is monochromatic restoration of the full color image .The luminance component Y cam be calculated as

$$Y = 0.299R + 0.587G + 0.114B \ . \tag{8}$$

where every coefficient reflects the sensitivity to each color. Experiments show that when we choose weighted ratio as R: G: B=2:1:4, it is the most beneficial to image quality [10]. We can see from the ratio that when we use luminance which is mixed by color components (R,G,B)as 1 unit, contribution ratio of the red light ,green light and blue light are2/7, 1/7 and 4/7 respectively .Using these ratios, we define CHPSNR as follows:

$$CHPSNR = 10\log_{10} \frac{3*m*n*\{\max(x)\}^2}{\sum_k \sum_{i,j} [\| h_{ijk} *(\frac{2}{7}e_{ijkr}) \|^2 + \| h_{ijk} *(\frac{1}{7}e_{ijkg}) \|^2 + \| h_{ijk} *(\frac{4}{7}e_{ijkb}) \|^2]} \ . \tag{9}$$

where e_{ijkr} ,e_{ijkg} and e_{ijkb} are error images of R, G and B level respectively.

5 Experiment Results

Here, we introduce the peak signal to noise ratio for color image [11]:

$$CPSNR = 10\log_{10} \frac{\max(x)^2}{\left(EMSr + EMSg + EMSb\right)/3} \ . \tag{10}$$

where EMSr, EMSg and EMSb are mean square error for R, G and B respectively.

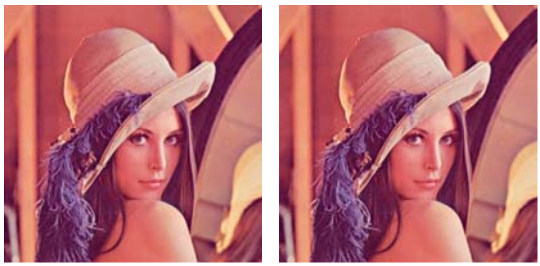
5.1 Effect of Color on Stego Image's Quality

Now, we'll give two examples to show the effect of color on stego image's quality.

Example 1: Hiding the same gray image into R, G and B level of Lena as shown in figure2 (a) respectively using LSB algorithm based on spatial domain, through which we acquire three stego images as shown in figure2 (b), figure2(c) and figure2 (d).

Example 2: Hiding the same secret messages into R, G and B level of Pepper as shown in figure3 (a) respectively using LSB algorithm based on spatial domain, through which we acquire three stego images as shown in figure3 (b), figure3(c) and figure3 (d).

(a) original image (b) R level embedded



(c) G level embedded (d) B level embedded

Fig. 2. Images hidden secret image at different level of Lena

(a) original image (b) R level embedded

(c) G level embedded (d) B level embedded

Fig. 3. Images hidden same secret messages at different level of Pepper

The calculated CPSNR and CHPSNR are shown in table 2.

Table 2. CPSNR, CHPSNR for different level

Color	Lena		Pepper	
	CPSNR	CHPSNR	CPSNR	CHPSNR
R	69.5320	110.7907	24.0093	46.1320
G	69.5067	106.9205	24.5865	36.4797
B	69.5331	122.4596	24.6103	49.1335

Experiment results are analyzed as follows:

(1) Results judged by human eyes. Comparing three stego images with original image in figure2, we can see after careful observation that some area on the top of the cap in stego images seems to be reddening, greening and bluing respectively. The image in figure2(d) is most close to the original one, which has the best quality; image in figure2(b) is worse than it; while image in figure2(c) has the worse quality. In figure3, we can clearly see that the image in figure3(d) is most close to the original one, while image in figure3(c) has the worse quality. These are decided by color masking of HVS. Human vision's sensitivity to blue is lowest, while sensitivity to green is highest. Therefore, when message is hidden in blue level, the stego image has the best quality.

(2) Results calculated by global CPSNR. As can be seen from table2, three CPSNRs of Lena and three CPSNRs of Pepper are very similar, which means that the three images have almost the same visual quality. Obviously, this result does not match with the truth.

(3) Results calculated by CHPSNR. Seen from table2, results evaluated by CHPSNR match with human eyes' subjective judgment.

5.2 Effect of Capacity on Stego Image' s Quality

In order to see the effect of embedded capacity on stego image' s quality, we use several typical steganography tools to hide different secret message into 1000 color images which are select from USC-SIPI Image Database and digital camera. Table3 summarizes CHPSNR results with some popular steganography tools.

Table 3. CHPSNR for different steganography tools with varies embedding capacity

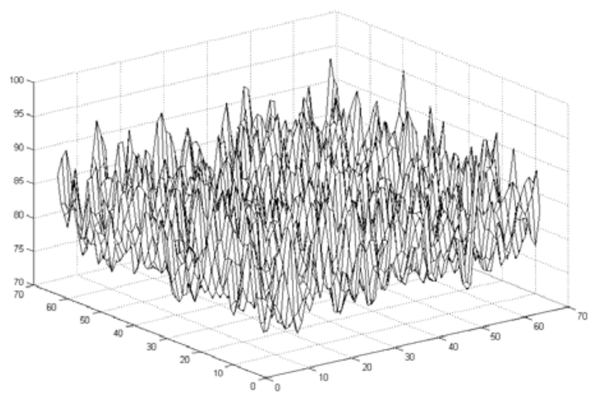
Capacity	S3en	HIP	Ezstego	Stash It	Jsteg-Shell
2%	75.8337	73.7605	60.9975	56.3697	49.4933
5%	68.7031	66.2222	49.8717	45.4717	39.7870
10%	63.0196	60.3883	44.0163	39.4814	36.1853
20%	60.6252	57.4525	38.7401	33.0271	-----
30%	58.0634	55.4314	-----	-----	-----
40%	55.4299	53.3794	-----	-----	-----

It can be seen from experiment results that:

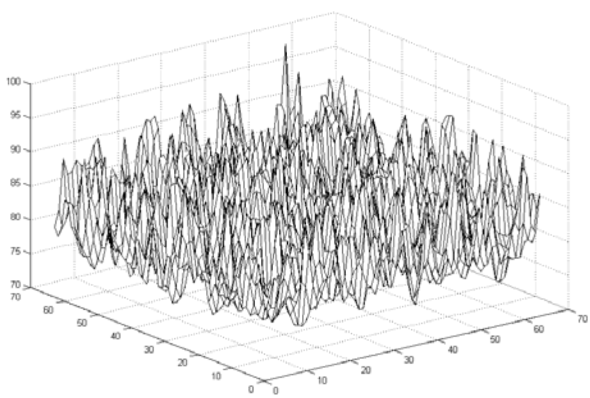
(1) S3en and Hide in Picture have the best imperceptibility, while Ezstego and Stash It are better than Jsteg-Shell, which matches with our direct observation.
(2) CHPSNR decreases with the embedding capacity; that is to say, CHPSNR relates capacity to quality evaluation.

5.3 Localized Distortion

In order to observe the local distortions intuitively, perception error of every block is expressed with graphic method. Distribution map for CHPSNR is shown in figure 4, where coordinates represent the position of CHPSNR, the block is 8*8 in our example.

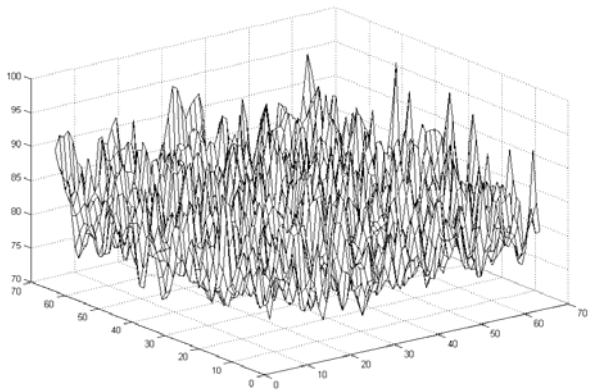


(a) R level



(b) G level

Fig. 4. HPSNR distribution map for each level of color stego image



(c) B level

Fig. 4. (*Continued*)

As can be seen from figure 4, local distortions of an image are different. There are differences among R, G and B level even in the same position. Investigating local distortions can help researchers to improve the steganographic algorithm, which will promote the development of steganography and steganalysis.

Therefore, we can draw the conclusion that the evaluation method proposed in this paper matches with HVS, which can effectively evaluate the imperceptibility of steganography.

6 Conclusions

In this paper, we discuss the effect of color on HVS sensitivity, on the basis of which the weighted values are calculated, and then an evaluation metric CHPSNR is proposed. Experimental results demonstrate that CHPSNR can well reflect the image degrades, which is consistent with HVS and can be used to evaluate the performance of steganography algorithm. We believe that this achievement is of great importance to research and application of information hiding, and will promote the development of information hiding algorithm and evaluation method.

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