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Perceptually tuned robust watermarking scheme for digital images

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Abstract

In this paper, we present a digital image watermarking scheme that uses both human visual system and statistical properties. The scheme places watermark in discrete cosine transform (DCT) domain and spreads the watermark effect on the entire image. We have compared our proposed scheme with two other popular schemes and shown that our proposed scheme yields better results in terms of transparency, robustness and maximal capacity requirements.

Keywords: Watermarking; Entropy masking; Bounded normal distribution

1. Introduction

A digital watermark, or watermark in short, is an invisible mark inserted in digital media such as digital images, audio and video so that it can later be detected and used as evidence of copyright infringement. However, insertion of such invisible marks should not alter the perceived quality of the digital media (it is a imperceptibility requirement) while being extremely robust to attack (it is a robustness requirement) and being impossible to insert another watermarks for rightful ownership (it is a maximal capacity requirement) (Cox et al., 1996; Podilchuk and Zeng, 1998).

In recent years, an overwhelmingly large amount of research work has been done in watermarking digital images for copyright protection. In this paper, we have discussed only two of the most recent and popular schemes proposed by Cox et al. (1996) and Podilchuk and Zeng (1998) and compared our proposed scheme with them. Cox et al. (1996) proposed a watermarking scheme based on the spread spectrum (SS) communication. In this scheme, DCT is performed on a whole image and then the watermark is embedded in a predetermined range of low frequency AC components. The embedded watermark signal consists of a sequence of real numbers that are normally distributed and it is scaled according to the signal strength of the frequency components. It is a

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simple watermarking scheme with perceptual weighting consideration. Consequently, Podilchuk and Zeng (1998) (P&Z) have extended this scheme using the Watson (1995) visual model to adapt the watermark to each image and they believe that it can provide a maximum length and maximum power watermark.

We further improved these schemes in this paper. Firstly, we incorporated excitatory–inhibitory interaction between cells into our model in order to maximize the watermark. Secondly, in P&Z's scheme, watermarked image shows image impairments because of the normally distributed watermark values that make the pixel values to exceed the just noticeable difference (JND). We used bounded normal (BN) distribution to overcome this drawback because it does not yield the values outside the range $[-1, 1]$.

2. Entropy masking model for maximal watermark

Our perceptual watermarking scheme provides a frequency domain technique and thus it is suitable to adapt with the Joint Picture Experts Group (JPEG) compression scheme. As shown in Fig. 1, the watermark insertion uses human visual system properties to make the watermark imperceptible with maximal strength. We extend the Watson visual model to achieve this task. Watson (1995) modeled three different properties of the human visual system: frequency sensitivity ($F_{u,v}$), luminance masking ($L_{u,v,b}$), and contrast masking ($C_{u,v,b}$) for each DCT coefficients as in the following equation.

$$L_{u,v,b} = F_{u,v}\left(\frac{X_{0,0,b}}{X_{0,0}}\right)^{\alpha}, \tag{1}$$

$$C_{u,v,b} = \max[L_{u,v,b},\ |X_{u,v,b}|^{\beta_{u,v}}(L_{u,v,b})^{1-\beta_{u,v}}], \tag{2}$$

where $X_{0,0,b}$ is a DC coefficient of the block b, $X_{0,0}$ is the average of all $X_{0,0,b}$s, which corresponds to the mean luminance of the display, $X_{u,v,b}$ is a (u, v)th DCT coefficient of the block b, and α and $\beta_{u,v}$ are set to 0.649 and 0.7 to control the degree of luminance sensitivity and contrast sensitivity, respectively.

In the human visual system, De Valois and De Valois (1990) reported that horizontal and amacrine cells transmit signals to the neighbor bipolar and ganglion cells, which inhibit their responses (i.e., lateral inhibition). Watson et al. (1997) suggested an entropy masking model in his paper, and we made a lateral inhibition model using an entropy masking as in the following equation

$$V_{u,v,b} = \max[C_{u,v,b},\ |C_{u,v,b}| \cdot (E_{u,v,b})^{\gamma}], \tag{3}$$

$$E_{u,v,b} = \sum_{x \in N(X_{u,v,b})} p(x) \cdot \log\frac{1}{p(x)}, \tag{4}$$

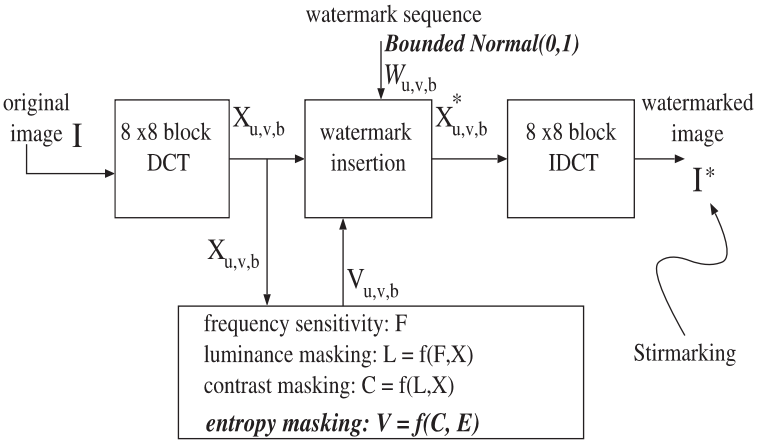

Fig. 1. Our perceptual watermarking scheme.

where $E_{u,v,b}$ is the entropy of $N(X_{u,v,b})$ which is a set of $X_{u,v,b}$'s eight neighbors, and $p(x)$ is the probability of x in a set $N(X_{u,v,b})$. We chose 0.5 for γ experimentally to make the $E_{u,v,b}$ work only when it is larger than 1.0. The γ can be adjusted to the noises of original images to improve the robustness and maximal capacity requirements. After identifying the threshold value for each DCT coefficients, we insert watermark into the coefficients as in $X^*_{u,v,b} = X_{u,v,b} + JND \cdot w_{u,v,b}$, where $X^*_{u,v,b}$ refers to the watermarked DCT coefficients, $w_{u,v,b}$ is the sequence of watermark values which take zero when $X_{u,v,b} \leqslant JND$ as in (Podilchuk and Zeng, 1998). We used $V_{u,v,b}$, which is always no smaller than $C_{u,v,b}$, for JND for our watermark sequence (maximal capacity requirement). We generated watermark $w_{u,v,b}$ using BN distribution to reduce the image impairment as will be shown in our experiment (imperceptibiliy requirement).

3. Simulation

In our experimentation, we simply used the JPEG (Pennebaker and Mitchell, 1993) quantization table for frequency sensitivity. Each entry of $F_{u,v}$ is set to the half value of the quantization table in the sense that a quantization step Q assumes $Q/2$ allowable distortions. For $L_{u,v,b}$ and $C_{u,v,b}$, we used the same value of α (0.649) and β (0.7) as the one from Watson (1995). Fig. 2 summarizes all the experimental parameters; frequency sensitivity $F_{u,v}$, luminance masking factor α, contrast masking factor β, and entropy masking factor γ.

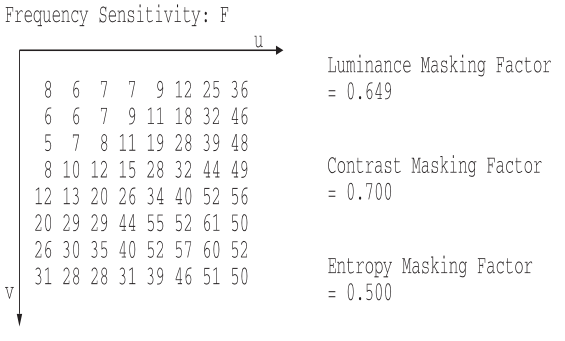

Fig. 2. Parameters for our experimentation.

We compared our watermarking schemes with P&Z's and SS scheme in terms of imperceptibility, maximality and robustness. Fig. 3 shows the watermarked images for *cameraman* after applying three watermarking schemes: SS scheme, P&Z's scheme, and the proposed scheme. We use these high contrast images for our demonstration because they are hard to insert watermarks in, so that we can easily show image artifacts after watermarking.

For the comparison of imperceptibility, we used objective and subjective quality degradation measure between original images and watermarked images. In the subjective quality assessment, the edges in general contribute significantly. Therefore we zoomed the image segment by segment and compared the visual quality loss along the edges (see Fig. 3). As shown in Fig. 3, SS and the proposed schemes show almost the same image quality as original image, while P&Z's scheme shows some image impairment along some edge portions. However, the objective quality shows little difference; signal to noise ratio (SNR) is 29.73 dB for Cox, 39.06 dB for P&Z, and 41.89 dB for the proposed scheme.

In Fig. 3, we can also see the difference images that show the embedded watermark. These difference images are amplified with the same factor to maintain the consistency in the results. The SS scheme has very little and small portional watermark that implies malicious users can insert invalid watermark. In this aspect, P&Z's scheme and our proposed method show maximal watermark, and they satisfy the maximal capacity requirement.

To compare the robustness of our scheme, we used Stirmark (Petitcolas et al., 1998) which is known to defeat all the watermarking system in the world. Stirmark basically simulates a resampling process: it introduces the same kind of errors into an image as we would expect if we print an image on a high-quality printer and then scan the image again with a high-quality scanner. Resulting images after Stirmarking usually do not show any degradations, but there is significant geometrical degradation of watermark in watermarked images. Our scheme shows relatively higher detection value (0.438 and 0.515) than the Cox scheme (-0.566 and -0.436) and P&Z's scheme (-0.130 and

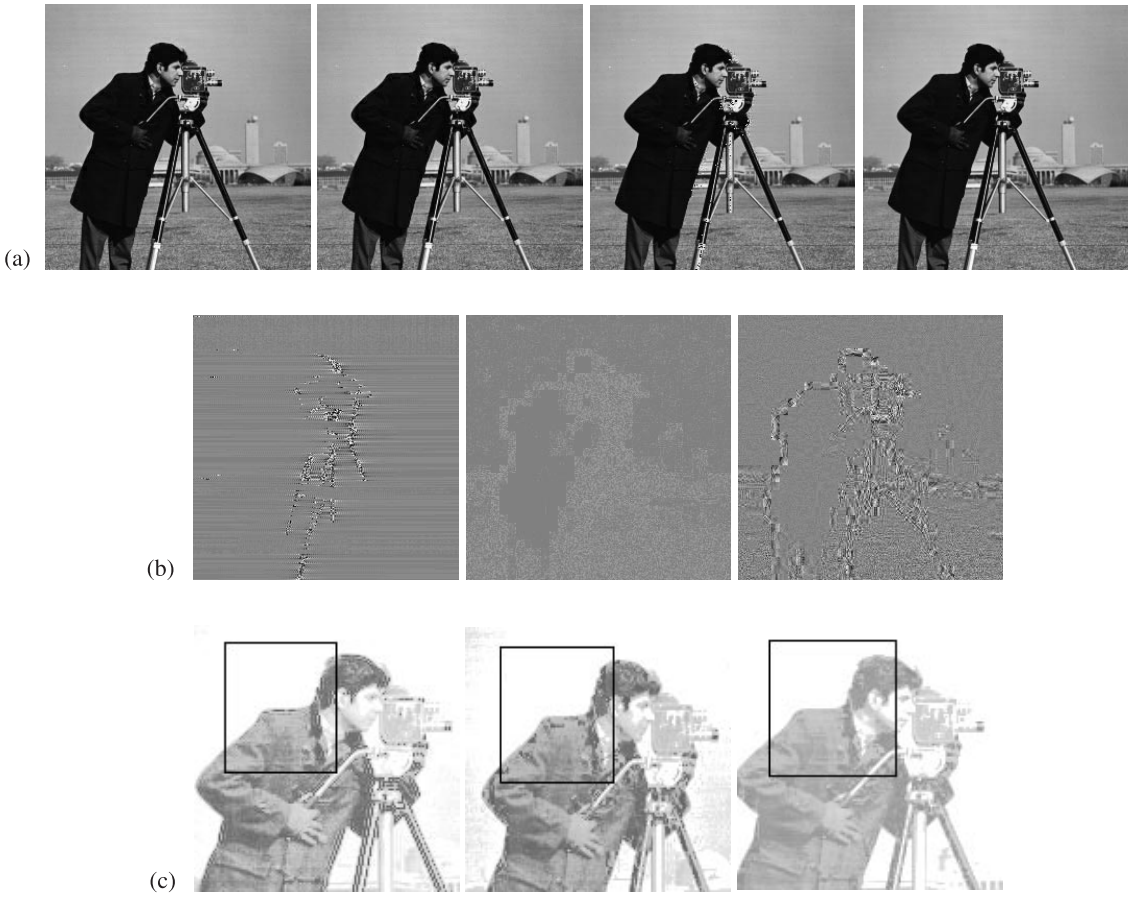

Fig. 3. (a) Original cameraman image, watermarked image using SS scheme, P&Z scheme, and our scheme, (b) different images after SS scheme, P&Z scheme, and our scheme (the watermark values can have negative values, and we adjusted the values to middle ground, +128 in case of 256 grey scale images, to display them), and (c) enlarged images: SS Scheme and P&Z scheme show noticeable image impairments along the edge portions, as shown highlighted within the box; our scheme shows no impairments.

−0.060) for lenna and cameraman images as shown in Fig. 4. This advantage comes from the fact that our watermark limits (i.e. bounded normal distribution effect) its values under wider (i.e. entropy masking effect) interval than the other two schemes.

4. Conclusion

In this paper, a perceptually tuned robust watermarking scheme for digital images has been proposed. We designed an excitatory–inhibitory model for perceptual watermarks to satisfy robustness and maximal capacity requirements. We used bounded normal distribution to reduce image impairments (imperceptibility requirement). We have shown that the proposed scheme provides better results than SS and P&Z's schemes in imperceptibility, robustness and maximal capacity requirements.

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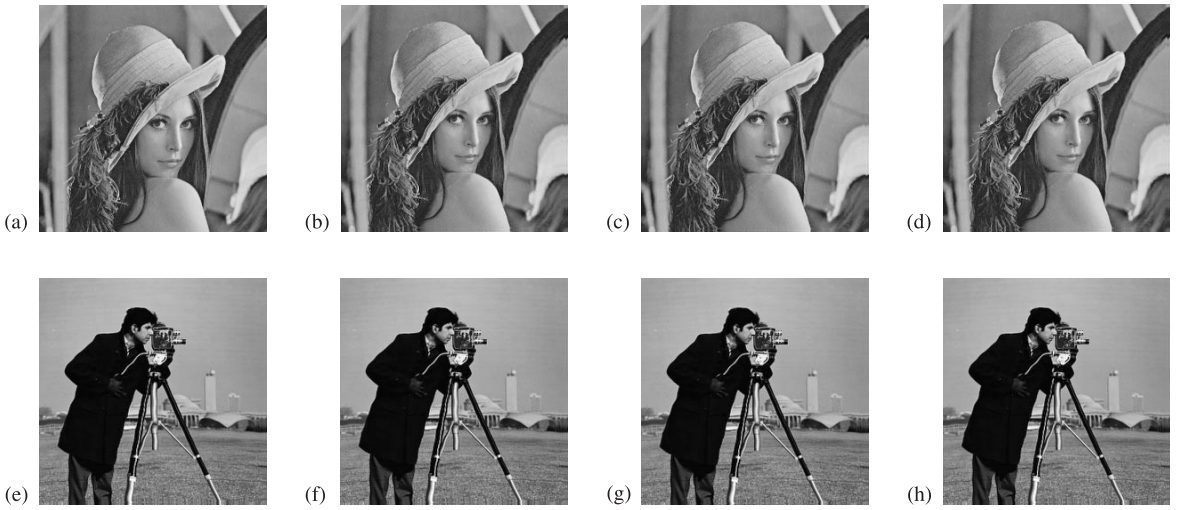

Fig. 4. (a) Original image, (b) Cox's, (c) Podilchuk's, and (d) our watermarked image after stirmarking; (e) original cameraman image, (f) Cox's, (g) Podilchuk's, and (h) our watermarked image after stirmarking.

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