PROGRESSIVE IMAGE WATERMARKING*

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ABSTRACT

Progressive transmission of images is very useful in many applications, especially in image transmission over the Internet. To view an image, people would want to see part of the image while the image transmission is in progress, rather than having to wait until the end of the image transmission. On the other hand, the ease of transmission and copying of images creates the need to use digital watermarking to embed the copyright information seamlessly into the media. In this paper, we propose a progressive image watermarking scheme. In this scheme, the watermark is embedded in such a way that we can retrieve part of it even when the watermarked image is still being transmitted. As transmission progresses, the retrieved watermark has a decreasing bit error rate. Our proposed methods not only transmit the watermarked image progressively, but also intelligently select watermark embedding locations robust to various attacks.

1. INTRODUCTION

With the prevalence of the Internet, more and more digital data can be accessed via the network. Internet users can store and transmit images without offering appropriate credit to the content owner. Digital watermarking techniques can solve the copyright protection problem by embedding owner information inside the image. Research activities in digital watermarking have been prosperous in recent years [1][2][3][4].

On the other hand, progressive image coding has been widely adopted, so that users can see a blurred or coarse version of the image while it is being transmitted. Users do not have to wait until the transmission is completed to see the image. Moreover, they can decide whether or not to keep waiting for the transmission depending on the partially transmitted image.

In this paper, we extend the concept of progressive coding to progressive watermarking. Consider the scenario that content providers want to have an efficient mechanism to verify any ownership information of the images people put on their web sites. They do not want to wait for downloading a whole image to verify its ownership. Progressive watermarking will provide a very efficient scheme for such tasks. It allows content providers to retrieve partial watermark information while the image is still being transmitted. Wang and Kuo [5] proposed the basic idea of integrating progressive image compression with the progressive watermark. In our paper, in addition to describing the progressive watermark concept in more detail, we explicitly show that as the progressive transmission gives us more information of the watermarked image, the bit error rate (BER) of the retrieved watermark image decreases. Moreover, an effective progressive watermarking system should take into consideration the way the image is transmitted, rather than simply progressively transmitting a watermarked image.

This paper is organized as follows. In Section 2, we introduce our proposed progressive watermark embedding methods together with watermark detection with decision fusion. In Section 3, we compare them under different noise environments. In the last section, we summarize our major contributions and outline the future work.

2. PROGRESSIVE WATERMARK

2.1 Watermark Embedding and Detection

We embed watermark in more robust Discrete Cosine Transform (DCT) coefficients of the original image based on the predicted attacks the DCT coefficients may suffer from the progressive transmission. We compare two methods of distributing watermark in the DCT coefficients. Method 1 embeds watermark in one DCT coefficient at each 8×8 block; Method 2 embeds watermark in multiple DCT coefficients at each block.

In addition to embedding watermark in a more robust way, we design a smart watermark detector that fuses the incoming DCT coefficients to retrieve the watermark. The watermark detector that fuses the received signals works as follows. Suppose we have k received signals, $y_1, y_2, \ldots, y_k$, carrying the same information bit q. Each bit q is multiplied by S_i, $i=1 \sim k$. With attacks, each qS_i is corrupted with noises $n_1, n_2, \ldots, n_k$ respectively. We assume that the noises are zero mean with variances $s_1^2, s_2^2, \ldots, s_k^2$. We want to determine whether q is 1 or -1 corresponding to bit one and zero.

$$y_i = q \cdot S_i + n_i, \qquad i = 1, \cdots, k \tag{1}$$

The test statistics

$$\hat{q} = \sum_{i=1}^{k} a_i \left(\frac{y_i}{s_i} \right) \tag{2}$$

has minimum variance with mean q if the watermark detector fuses received signals with weights a_i.

$$a_i = \frac{S_i^2 / s_i^2}{\sum_{j=1}^{k} S_j^2 / s_j^2} \tag{3}$$

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If we use zero as decision boundary, which means the detected result is bit one if $\hat{q} \geq 0$ and the detected result is bit zero otherwise, the probability of watermark detection error is

$$P_e = Q\left(\sqrt{\sum_{i=1}^{k} \frac{S_i^2}{s_i^2}}\right) \tag{4}$$

where *Q(x)* is the *Q*-function for the area under the right tail of the Gaussian distribution function.

Given the same watermarked image quality, that is, the same total watermark power,

$$\sum_{i=1}^{k} S_i^2 = C \tag{5}$$

we can allocate the watermark power to have a more robust watermark. The watermark power should be allocated to a single DCT coefficient in which the noise variance is the smallest.

$$S_r^2 = C, \qquad s_r^2 \leq s_i^2, \ \forall i \neq r \tag{6}$$

This allocation scheme is a special case of embedding the watermark bit to the DCT coefficient with the largest signal (watermark) to noise ratio [6][7].

In reality, the attacks the watermarked image suffers may not be exactly the same as our assumption. We want to distribute the watermark in multiple DCT coefficients to reduce the risk of allocating all watermark bits in the noisier DCT coefficients.

2.2 Proposed Progressive Watermarking Scheme

- Watermark Embedding:
  1. Perform 8×8 blockwised DCT to the original image.
  2. Calculate the predicted noise variances of the 63 zigzag ordered DCT coefficients (excluding the DC term). Noises considered are JPEG quantization noise and Gaussian noise. More noises can be taken into account. Different ways of embedding watermark will be discussed later in Method 1 and 2.
  3. Embed each bit of the watermark image to its corresponding block in the original image. The DCT coefficient is raised to embed bit "1" and is lower to embed bit "0".

- Progressively Transmitting the Watermarked Image

  JPEG progressive coding has two modes: the *spectral selection* and the *successive approximation.* The two modes correspond to different grouping of the DCT coefficients. We use the former to transmit the watermarked image progressively. DCT coefficients are zigzag ordered. DC coefficient of every block is sent first, then follows the first low frequency AC coefficient, and so forth. Since there are 64 zigzag ordered coefficients, there are 64 "*stages*", stage 0 to stage 63, in the progress of transmission.

- Watermark Detection:
  1. In every stage, subtract DCT coefficients of the original image from those of the transmitted watermarked image. Since this is a private watermarking scheme, the receiver can calculate exactly the same watermark embedding locations as the sender. Fuse the subtracted DCT coefficients by equation 2.
  2. Reconstruct the watermark image by the retrieved bit in each block of the transmitted watermarked image.

Next we describe in detail two watermarking methods: Method 1 and Method 2.

Method 1:

- Choose one AC coefficient with the smallest variance among the first *N* AC DCT coefficients to embed watermark. The detector uses the first *N* AC DCT coefficients to retrieve the watermark. In progressive transmission, the detector may stop detection before the whole image has been transmitted. The number *N* is smaller or equal to 63.

Method 2:

- At each stage, the embedder will check if the variance of this DCT coefficient at this frequency is smaller than the one we choose to embed watermark bit before. It embeds watermark bit at this frequency if the variance is smaller. This process starts from embedding at the first AC coefficients and continues until the stage is beyond *N*. Since the same watermark bit is embedded for multiple times, the amplitude must be reduced to achieve the same watermarked image quality, i.e., the same peak signal to noise ratio (PSNR) of the watermarked image with respect to the original image.

3. EXPERIMENTS

3.1 Experimental Setup

The watermark image we use is a binary image of size of 8×8 (Figure 1(b)). Each bit is distributed into 64 randomly selected blocks of the original image. The original image is an 8-bit graylevel 512×512 image (Figure 1(a)). Figure 1 shows an example of a watermarked image by Method 2 being progressively transmitted under both JPEG quantization and Gaussian noise.

The predicted noise we use consists of two terms: Gaussian noise in DCT coefficients with average variance of 100 and JPEG quantization noise with quality factor 50. The Gaussian noise has larger noise variance in lower frequency terms considering that the intentional attacker might want to invalidate the watermark detection in the earlier stages of the progressive transmission. The Gaussian noise added to each DCT coefficient is of variance $(64-k)p^2, k = 0 \sim 63$, where k is the zigzag ordered DCT coefficient index and p is a scale factor that can be adjusted to get the desired average noise variance.

We choose the first 9 AC coefficients, i.e. *N*=9, in our experiments. Using Equation (6), Method 1 embeds watermark only in the 9th AC coefficients of the original image, $C=S_9^2=20$. Method 2 embeds watermark in the 1st, 2nd, 4th, 5th, 8th, and 9th AC coefficients,

$$S_1^2 = S_2^2 = S_4^2 = S_5^2 = S_8^2 = S_9^2 = 20/6$$

according to the algorithm described in Section 2.2.

We compare the two progressive watermark methods with the same watermarked image quality—the same total watermark power. We choose a small power, *C*=20, in our experiment. In this case, even if all watermark power is distributed into one DCT coefficient at each block, we will not introduce too serious perceptual artifact to the watermarked image.

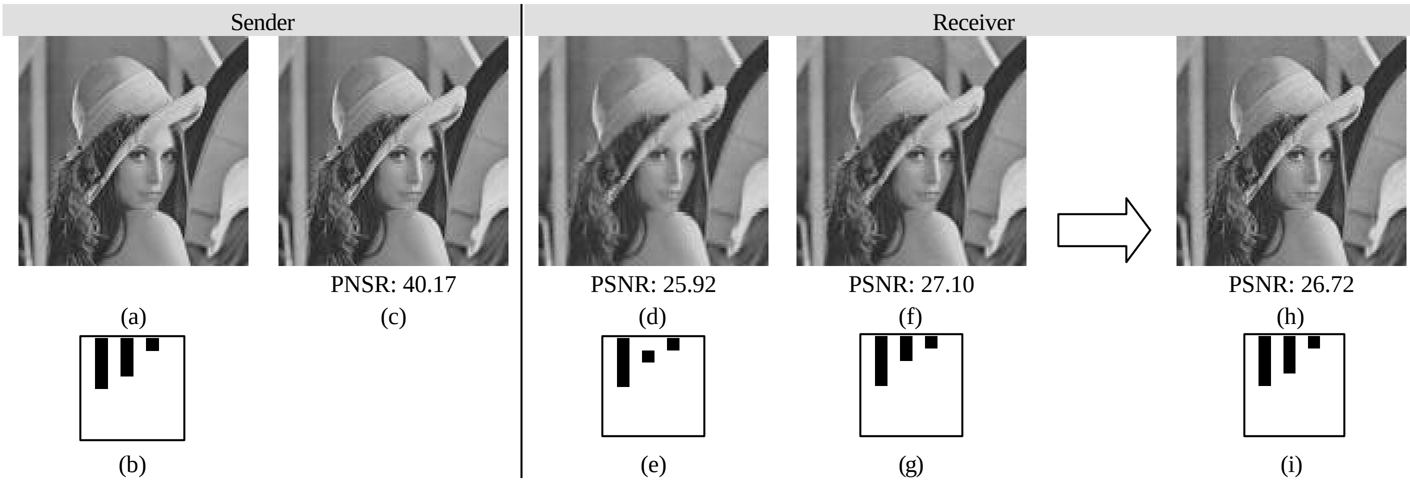


Figure 1. (a) Original image: Lena; (b) Watermark image: checkerboard; (c) Watermarked image; (d)Transmitted watermarked image under Gaussian noise of average variance 100 and JPEG quality factor 50 by Method 2 at stage 1 (first AC coefficients are sent); (e) Retrieved watermark at stage 1; (f) Transmitted watermarked image at stage 3; (g) Retrieved watermark at stage 3; (h) Transmitted watermarked image at final stage 63; (i) Retrieved watermark at stage 63;

3.2 Progressive Watermarking Performances with Matched and Unmatched Noise Predictions

In this section, we evaluate the two watermark methods under different noise environments. The noise environments associated with Figure 2 have the same quantization level as we predict—quantization of quality factor of 50. In addition to quantization noise, there are Gaussian noises added. The noise environments associated with Figure 3 have the same average Gaussian noise variance as we predict—Gaussian noise of average variance 100. Likewise, there are also quantization noises involved.

- **Decreasing BER**

Both progressive watermarking methods have decreasing BER as the detectors receive more and more information bit from the watermarked image. After stage 9, the BER stop dropping because there is no more watermark information bit coming in while the watermarked image is still in transmission. From Figure 2 and 3, the watermark detection errors drop to zero for both methods. The only exception is in Figure 3 (a) when the quantization is very heavy. Method 1 has more chances of surviving the quantization by concentrating all watermark power in one DCT coefficient at each block. However, in this case, the image is so blocky that its value of usage is degraded.

In Figure 2 and 3, the watermark detection BER of Method 1 does not drop smoothly as that of Method 2. Since Method 1 embeds watermark only in the 9^{th} AC coefficients, the detector will not receive watermark bit until the 9^{th} stage. Thus we prefer Method 2 because we do not have to wait until stage 9 to get the watermark information.

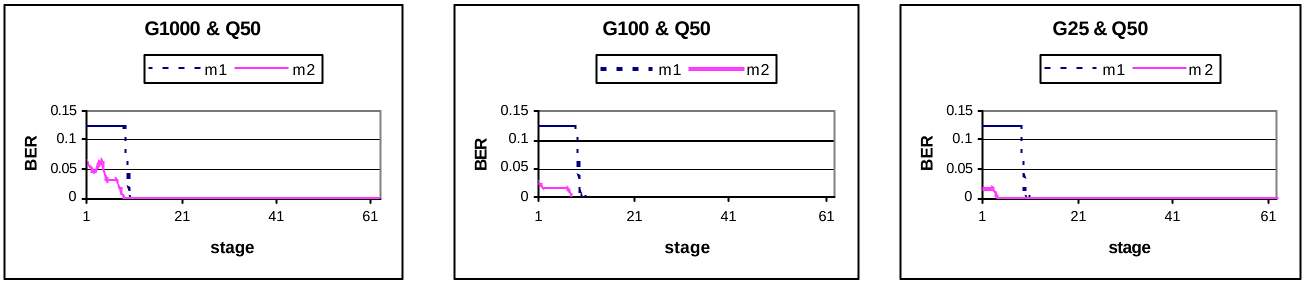
- **Matched Noise Environments**

When the noise environment is the same as what we predict, Method 1 performs better (Figure 2(b) or Figure 3(b)). This result follows what we expected in Equation (6). It is better to distribute all the watermark power to the less noisy DCT coefficient if we know how the noises are distributed.

- **Unmatched Noise Environments**

When the noise environment differs from what we predict, if the order of the noise variance is the same as the order of our predicted noise variance, Method 1 performs better. The DCT coefficients embedded with watermark are less noisy. We should expect Method 1 to be better than Method 2 after stage 9 in Figure 2(a) and Figure 3(c). The experiment result shows Method 1 and 2 both have the same retrieved result with error zero after stage 9^{th}. At this point, they are both good. We shall see the effect of Method 1 better than Method 2 when the noise introduced is larger. However, this kind of noisy environment is not realistic because the attacker would not want to corrupt the image quality too much to degrade the value of the image.

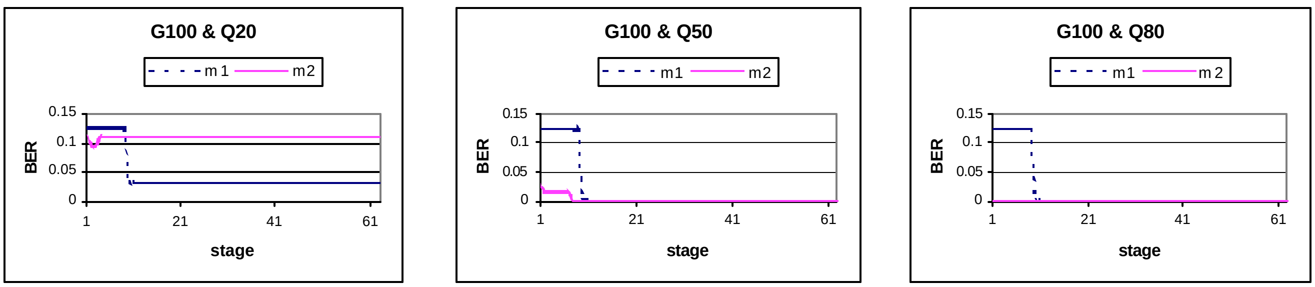
If the noise variances are in such an order that is different from what we predict, Method 2 can retrieve watermark from many coefficients including less noisy DCT coefficients and more noisy ones while Method 1 can only retrieve watermark from the more noisy DCT coefficients. In this case, Method 2 performs better (Figure 2 (c)).



(a) (b) (c)

Figure 2. Watermarked image in transmission under JPEG compression of quality factor 50 and different Gaussian noises. "m1" refers to Method 1 while "m2" refers to Method 2. (a) Gaussian noise of average variance 1000; (b) Gaussian noise of average variance 100; (c) Gaussian noise of average variance 25.

The PSNR of the watermarked image after the transmission is completed: (a) 17.96; (b) 26.72; (c) 30.14



(a) (b) (c)

Figure 3. Watermarked image in transmission under Gaussian noise of zero mean and average variance of 100 and different quality factor of JPEG quantization. (a) quality factor 20; (b) quality factor 50; (c) quality factor 80.

The PSNR of the watermarked image after the transmission is completed: (a) 25.77; (b) 26.72; (c) 27.22

4. CONCLUSION

We successfully implement two progressive watermarking methods in a sense of decreasing BER of the retrieved watermark image. Method 1 performs well only if the noise environment matches what we predict when we embed the watermark. In reality, the noise environment differs from what we predict with reasonable degree of attack. Method 2 performs much better by distributing the watermark to reduce the risk of allocating all watermark information only in noisy coefficients.

In our experiment, we embed watermark with a small power to ensure watermarked image quality. According to the characteristic of the human visual system (HVS), we can use larger watermark power in some DCT coefficients without introducing visual artifacts, thus further improve performance of the watermark system. We will apply HVS to our system in the future.

Not only the content providers, but also the users want to progressively download and verify ownership information of the images on the web. In addition, the watermark detector might not have the knowledge of the original image. We will extend our methods from a private scheme to a public scheme to meet this need.

5. REFERENCES

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