Multiple Watermarking for Compressed Sensing with Robust Transmission Applications

Hsiang-Cheh Huang
National University of Kaohsiung
Kaohsiung, Taiwan, R.O.C.
hch.nuk@gmail.com

Feng-Cheng Chang
Tamkang University
Ilan, Taiwan, R.O.C.
135170@tku.edu.tw

Yuh-Yih Lu
Minghsin University of Science and Technology
Hsinchu, Taiwan, R.O.C.
yylu@must.edu.tw

Yi-Hsin Pang
National University of Kaohsiung
Kaohsiung, Taiwan, R.O.C.
yhpang@nuk.edu.tw

***Abstract*—Compressed sensing (CS) is a new research branch in multimedia compressing, which is famous for its superior performance. Due to its digital nature, it is easy to copy and distribute the compressed files in digital format, and the issues relating to digital rights management (DRM) applications would be in urgent need. We propose to hide multiple watermarks in compressed sensing coefficients. Color images consisting of three color planes with high correlations are selected for watermark embedding. Multiple watermarks are embedded into the CS coefficients corresponding to different color planes. With our method, watermarked images are suitable for transmitting over lossy channels, while the copyright of color images can be retained. Simulations have presented the effectiveness for the proposed algorithm.**

Keywords—compressed sensing; multiple watermarking; color planes; robust transmission

I. Introduction

Compressed sensing [1][2] provides an innovative way for multimedia compression. With compressed sensing, the major goal is to reach the superior compression ratio, which implies that the filesize at the output should be only a fraction to the original image, or its counterpart at the encoder. With compressed sensing, it composes to major principles, namely, *sparsity* and *incoherence*. Sparsity keeps the characteristics of original images, and incoherence relates to the sensing modality. At the encoder, comparing to the encoder input, a small number coefficient at the encoder output can be reached, leading to the superior performance in compression ratio. At the decoder, by use of L1-norm minimization, reconstructed image can be obtained from the very small amount of CS coefficients.

Besides, copyright protection of multimedia plays an important role for practical applications [3][4], and we plan to embed watermarks with CS. For watermarking with compressed sensing, we make use of the high correlations between color planes of color images, and embed multiple watermarks into the compressed sensing coefficients. Our method performs well for the transmission over loss channels. Therefore, copyright protection of color images with compressed sensing can be reached.

We present this paper follows. In Sec. II, we describe the multiple watermarking algorithm for color images with compressed sensing. We provide the simulation results with different settings in Sec. III. And we address the conclusion of this paper in Sec. IV.

II. The Multiple Watermarking Algorithm with Compressed Sensing

In this paper, we first apply discrete cosine transform (DCT) to the original image to reach a sparse signal $\mathbf{X} \in R^N$. With compressed sensing, we obtain the measurement $\mathbf{Y} \in R^M$. Here, $M \ll N$, leading to the underdetermined system. The composition of orthogonal basis leads to sensing matrix $\mathbf{\Phi} \in R^{M \times N}$ at the encoder. At the decoder, due to the underdetermined condition, a constrained optimization problem should be solved to look for the reconstruction [5].

We aim to propose the multiple watermarking algorithm with compressed sensing for color images, which is suitable for robust delivery over lossy channels. Steps for watermark embedding can be described as follows.

Step 1. Separate the original color image into the red (R), green (G), and blue (B) planes, and apply compressed sensing to each layer.

Step 2. Choose one color plane as the reference, and the other two for watermark embedding.

Step 3. Suppose the blue (B) plane is served as reference. We choose the CS coefficients in the red (R) plane, $y_{R,i}$, as an instance, and those in the green (G) plane can be applied accordingly. Watermark can be embedded into CS coefficients $y_{R,i}$ by

$$\hat{y}_{R,i} = \begin{cases} y_{R,i} + w, & \text{if } \left| y_{R,i} - y_{B,i} \right| < T_E,\ i = 1, 2, \cdots, K; \\ y_{B,i}, & \text{otherwise.} \end{cases} \quad (1)$$

Here, T_E is the threshold and K is the watermark length.

Step 4. Transmit the watermarked coefficients in Eq. (1) in the red and green planes, and the CS coefficients in the blue plane over lossy channels.

Step 5. Reconstruct watermarked image at the decoder with L1-minimization, and extract the watermark bits.

III. Simulation Results

We have employed the original image `building`, taken by the authors, having the size of 256×256 in Fig. 1(a), to conduct simulations for multiple watermarking. With compressed sensing, 1000 coefficients from sparsity and 20000 coefficients from incoherence are selected for experiments. Regarding to the assessments of proposed method, we employ both the peak signal to noise ratio (PSNR) and the structured similarity (SSIM) [6] to present

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the watermarked image quality, and the length of the watermark to expressed the watermark capacity.

In Fig. 1(b), after embedding multiple watermarks into the red and green planes, watermarked reconstruction leads to the PSNR of 26.76 dB and the SSIM of 0.7295. Fig. 1(b) can be regarded as lossless transmission of watermarked image, thus the extracted watermark has the bit correct rate (BCR) [3] of 1.0000. In Fig. 1(c) and Fig. 1(d), they denote the transmission of CS coefficients in the red, green, and blue planes, and all are experiencing 10% or 20% data loss, respectively. Due to the possible loss of CS coefficients during transmission, watermarked reconstructions get deteriorated with the increase of loss rates. The BCR values are still high to protect the copyright of color image, even though slight decrease in BCR can be observed with the increase of lossy rate. With the simulation results provided, the proposed multi-watermarking method is suitable for robust transmission of watermarked images based on compressed sensing.

IV. Conclusions

In this paper, we propose a robust multiple watermarking algorithm, which is suitable for the lossy transmission of color images with compressed sensing. We apply compressed sensing into the three color planes of original image, and then we embed multiple watermarks into the CS coefficients corresponding to different color planes for the digital rights management applications. After transmission over lossy channels, watermarked CS coefficients, which may be lost during transmission, could be reconstructed at the decoder to obtained the reconstructed image. Subsequently, the embedded watermarks can be extracted accordingly to ensure the robustness of the algorithm, and hence the copyright of the image. Both the acceptable quality of reconstruction and the high correct rate of extracted watermarks can be reached. From the discussions above, our algorithm can be applicable for robust transmission of watermarking with compressed sensing.

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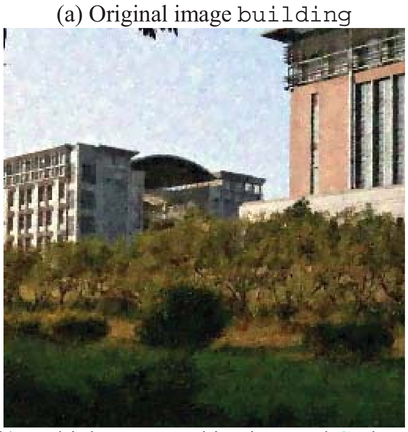
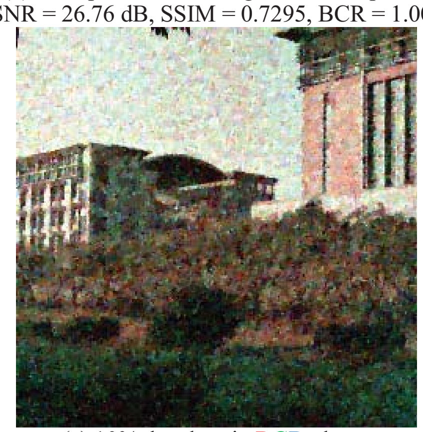
(a) Original image `building`



(b) Multiple watermarking in R and G planes
PSNR = 26.76 dB, SSIM = 0.7295, BCR = 1.0000



(c) 10% data loss in RGB planes
PSNR = 21.17 dB, SSIM = 0.3679, BCR = 0.9653

(d) 20% data loss in RGB planes
PSNR = 19.17 dB, SSIM = 0.2760, BCR = 0.9413

Fig. 1. Simulations of watermarked image after lossy transmission. (a) Original image. (b) Watermarked image. (c) 10% loss. (d) 20% loss.