Improved Differential Energy Watermarking (IDEW) Algorithm for DCT Encoded Image and Video

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Abstract: This paper addresses the real-time requirement of video watermarking and proposes a new improved DEW-based algorithm, which employs two measures to improve the DEW algorithm's performance. One is using the ratio of energy difference to total energy R_D to replace energy difference D as pattern to embed label bits. The other is that the selection of embedding cut-off index c doesn't need that both *lc-subregions* A and B have enough energy. The experimental results show that the improved algorithm performs better on watermark's visual quality impact, capacity and robustness than the original DEW algorithm.

Key words: Video Watermarking, Real-time, Improved Differential Energy Watermarking (IDEW), DEW

1. Introduction

As a main method for copyright protection of digital video data, video watermarking has gradually become a focus. However, unlike still image, video watermarking technology must meet the real-time requirement[1]. In order to meet the real-time requirement, the complexity of the watermarking algorithm should obviously be as low as possible.

Moreover, if the watermark can be inserted directly into the compressed stream, this will prevent full decompression and recompression and consequently, it will reduce computational needs. This philosophy has led to the design of very simple watermarking schemes. However, nearly each compressed video watermarking method has its own disadvantages, such as high complexity[3,4,5], low payload, less robustness[6,7,8,9] and visual artifacts[2] etc. The differential energy watermarking (DEW) algorithm proposed by Langelaar[7,9] seems to overcome these disadvantages and promising to be the best choice for real-time watermarking. But its disadvantages still exist, such as less robustness. As represented in figure 14 in [10], the bit errors can increase to 21% if the video bit-rate is decreased by 38%.

In order to improve the three performance criteria, we propose two improved measures as follows:

- Use *ratio of energy difference to total energy* R_D to replace *energy difference* D as pattern to embed label bits.
- The selection of embedding *cut-off index* c doesn't need that both *lc-subregions* A and B have enough energy. Only one of them, A or B (whose selection depends on the sign of the embedded bit), needs to have sufficient energy.

We consider that these measures can improve the watermark's robustness, visual quality impact, and capacity. In this paper we will present the improved scheme and an evaluation of its performance. For describing easily, we call the improved method as the IDEW algorithm.

This paper is organized as follows. In Section 1 a brief introduction to the problem is given and two measures are proposed to improve the DEW algorithm. In Section 2, the DEW algorithm is briefly described and the improved scheme is explained in detail. In Section 3, the experiment results are presented. In Section 4, the conclusions are drawn.

2. The Improved DEW algorithm

2.1. Review of the DEW algorithm

The DEW algorithm embeds watermark bits into an MPEG stream by enforcing energy difference between certain groups of 8×8 DCT blocks of the I-frames to represent either a '1' or a '0' watermark bit. The energy difference is enforced by selectively removing high frequency components from the DCT blocks.

The fact that a watermark is added only by removing coefficients has two advantages. One is that the DEW algorithm has only half the complexity of other coefficient domain watermarking algorithms. The other is that removing coefficients will always make the watermarked compressed video stream smaller in size than the unwatermarked video stream.

2.2. The Improved DEW algorithm

Comparing with the original DEW algorithm, the improved method employs two measures. Firstly it uses *ratio of energy difference to total energy* R_D to replace *energy difference* D (used in the DEW algorithm) as pattern to embed label bits. Secondly the selection of embedding *cut-off index* c doesn't need that both *lc-subregions* A and B have enough energy. Only one of them, A or B, needs to have sufficient energy. The following subsections will give a detailed description.

2.2.1. The ratio of energy difference to total. In the extraction procedure of DEW algorithm, to find the cut-off index, a value of the enforced energy difference D' is chosen and never changes in spite of any hostile or nonhostile attack. A label bit cannot be extracted correctly if the extraction cut-off index is smaller than the embedding cut-off index (i.e., $c_{extract} < c_{embed}$). If the reencoding attack happens, some AC-coefficients at high frequency are quantized to zero. If the value of D' remains unchanged, the extraction cut-off index must be smaller than the embedding cut-off index. So the extraction must result in more bit errors. It could be testified by Figure 1, which shows the block-average energy difference calculated by removing the coefficients of Lena and its attacked copy (*Quality*=10) in one subregion of each lc-region after cut-off index. Assuming the number of blocks is 32 and the value of D' is set at 6, the block-average energy difference could be calculated as 0.19, the cut-off index extracted from the original image is 34, however the cut-off index extracted from the attacked copy (Q=10) is 8, which may result in bit error.

In order to minimize the bit errors, the extraction cut-off index must approach the embedding cut-off index. This can be satisfied if the enforced energy difference D' could be self-adapted in terms of the practical total energy. However this can be hardly done because the enforced energy difference D' is only chosen once by experience (i.e., needs many experiments test in the DEW algorithm). Considering the total energy, we define R_D as *ratio of energy difference to total energy*, so that:

$$R_D = \frac{D}{E_A|_{c=0} + E_B|_{c=0}} \qquad (1)$$

R_D' represents what percentage of energy should be enforced in an lc-region. In Figure 2 an example is given of R_D calculated by removing the coefficients of Lena and its attacked copy (Q=10) in one subregion of each lc-region after cut-off index. Although the image is compressed with very low quality (Q=10), the curve still approaches closely to the origin. If the extraction ratio R_D' is chosen as a certain value, the cut-off index extracted from the attacked copy is very close to that gained from the original image. In Figure 2 if R_D' is set at 0.001, the cut-off index extracted from the attacked copy is 13, which is only one less than that gained from the origin.

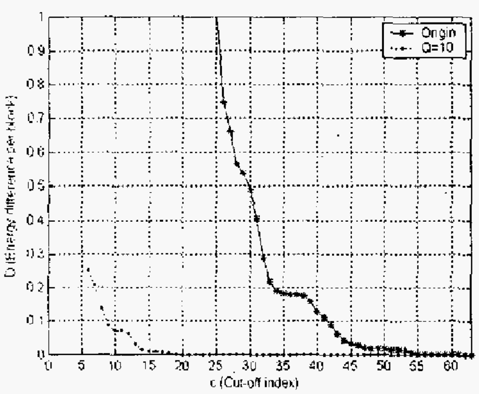

Figure 1. Block-average energy difference of Lena dependent on cut-off index

Using the ratio of energy difference to total energy R_D to replace energy difference D has two advantages. Firstly, it can avoid the bit errors which are introduced during embedding process because the image (or I-frame) has not enough energy content to make certain energy difference. Although the Ratio R_D keeps unchanged, the enforced energy difference varies in proportion to the total energy. So the case that the image has insufficient energy content to make certain energy difference never occurs. Secondly, it can lower the bit errors which are introduced during extraction process because of the distortion of the watermarked frame due to attacks. Using Ratio R_D can decrease the cut-off index difference between extracted from the attacked copy and from the original image.

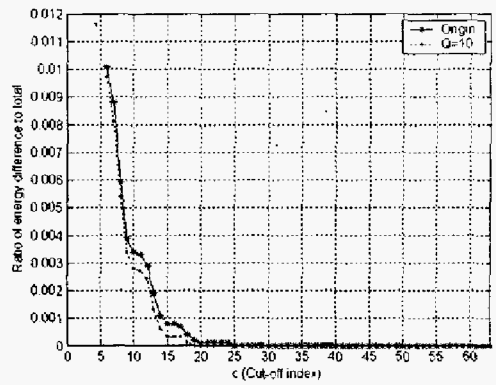

Figure 2. Ratio of energy difference to total energy of Lena dependent on cut-off index

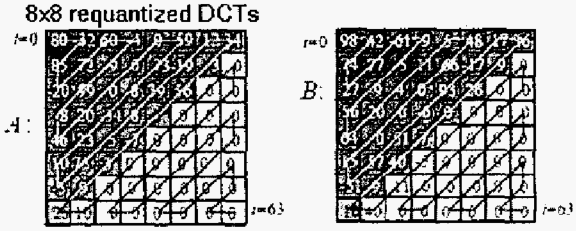

Figure 3. Embedding a label bit in an lc-region of n=2 DCT blocks.

2.2.2. The selection of embedding cut-off index. In the DEW algorithm, the cut-off index c is dependent on the energy difference. Its selection needs that both subregions A and B have energy larger than the required difference D, as that:

$$c(c_{\min}, n, D) = \max\{c_{\min}, \max\{g \in \{1,63\} \mid (E_A(g,n) > D) \,\&\&\, (E_B(g,n) > D)\}\} \qquad (2)$$

The key issue of the selection is keeping the energy difference between subregion A and B larger than the desired difference. But it doesn't really need that both subregions have energy larger than the required difference D. Our selection of cut-off index is presented as:

IF (b_j=0) THEN

$$c(c_{\min}, n, D) = \max\{c_{\min}, \max\{g \in \{0,63\} \mid (E_A(g,n) > D)\}\}$$

ELSE

$$c(c_{min}, n, D) = \max\{c_{min}, \max\{g \in \{0,63\} \mid (E_B(g,n) > D)\}\} \quad (3)$$

These can also meet the desired difference. The extraction cut-off index could be found according to Eq. (4), which is the same as the DEW algorithm.

$$c^{(extract)}(n, D') = \max\{\max\{g \in \{1,63\} \mid E_A(g,n) > D'\}, \max\{g \in \{1,63\} \mid E_B(g,n) > D'\}\} \quad (4)$$

The new embedding method has the same effect on the robustness as the DEW method, but it performs better on visual quality impact. This can be testified by the following example, which is illustrated in Figure 3. If the embedded bit is 1, for the DEW method, the embedding cut-off index is 35; while for the improved method, the embedding cut-off index is 36.

2.2.3. The embedding & extraction procedure. The embedding process is described as the following steps:

1) Shuffle all luminance DCT blocks of an image or I-frame pseudorandomly
2) Choose some global Parameters (R_D, n)
3) For all label bits b_j in label string L Do
   - The n blocks constitute an lc-region. Choose n/2 blocks to constitute A-subregion, another n/2 to constitute B-subregion
   - Calculate the practical cut-off index c for each lc-region:

     IF (b_j=0) THEN

     $c(c_{min}, n, D) = \max\{c_{min}, \max\{g \in \{0,63\} \mid (E_A(g,n) > D)\}\}$

     ELSE

     $c(c_{min}, n, D) = \max\{c_{min}, \max\{g \in \{0,63\} \mid (E_B(g,n) > D)\}\}$

     where $D = R_D \times (E_A|_{c=0} + E_B|_{c=0})$.

     IF (b_j =0) THEN discard components of area B in $S(c)$; IF (b_j =1) THEN discard components of area A in $S(c)$
4) Shuffle all luminance DCT blocks back to their original locations

The extraction process is described as the following steps:

1) Shuffle all 8×8 luminance DCT blocks of an image or I-frame pseudorandomly
2) Choose the extraction ratio R_D'
3) For all label bits b_j in label string L Do
   - The n blocks constitute an lc-region. Choose $n/2$ blocks to constitute A-subregion, another $n/2$ to constitute B-subregion
   - Calculate the practical cut-off index c for each lc-region:

     $$c_{extract}(n, D') = \max\{\max\{g \in \{1,63\} \mid E_A(g,n) > D'\}, \max\{g \in \{1,63\} \mid E_B(g,n) > D'\}\}$$

     where $D' = R_D' \times (E_A|_{c=0} + E_B|_{c=0})$.
   - Calculate number difference:

     $$D' = E_A(c_{extract}, n) - E_B(c_{extract}, n)$$

     IF (D' > 0) THEN b_j=0 ELSE b_j=1.

3. Experiment and discussion

We test the IDEW algorithm to see its performance in terms of watermark's visual quality impact, capacity and robustness. The "flower-garden" video sequence is used as test sequence. The sequence lasts 5 seconds, has a size of 352×240 pixels, is coded with 30 fps, has a GOP-length of 15 and contains P-, B- and I-frames. This sequence coded at different bit-rates (148, 222, 278, 314, 389, 518, 667, 833, 1000, 1055 and 1148 kbit/s) is used for all experiments in the following parts. For the DEW algorithm, the embedding enforced energy difference is set at 21315 (i.e., D=21315), the minimal cut-off point is set at 6 (i.e., C_{min}=6) and the extraction enforced energy difference is set at 533 (i.e., D'=533). For the IDEW algorithm, the embedding ratio of energy difference to total energy is set at 0.002 (i.e., $R_D = 0.002$), the minimal cut-off point is set at 6 (i.e., C_{min}=6) and the extraction number difference ratio is set at 0.00005 (i.e., $R_D' = 0.00005$).

The visual quality is assessed objectively by calculating the time-averaged *PSNR* value. The *PSNR* curve of the IDEW algorithm is above the curve of the DEW algorithm. An example of such behavior of the *PSNR* curves is shown in Figure 4. For the IDEW algorithm, the embedding ratio of energy difference to total energy is set at 0.002 (i.e., $R_D = 0.002$). For the DEW algorithm, the Enforced energy difference is calculated by eq. (5).

$$D = R_D \times (E_A|_{c=0} + E_B|_{c=0}) \quad (5)$$

Figure 4 shows that the IDEW algorithm performs better in visual quality than the DEW algorithm.

The watermark capacity is determined by the number of 8×8 DCT blocks that are used to embed one label bit. The label bit-rate is in inverse proportion to n. Doubling n could halve the label bit-rate. As n increases, the value of *PSNR* increases too, and the watermark is more robust (i.e. less Bit errors). The results of the experiments are presented in Table 1. It shows the algorithm could get a high *PSNR* (above 37.5db) when the number of blocks is set above 16. To compare with the DEW algorithm, we applied the IDEW algorithm to the sequence coded at different bit-rates. The result is listed in Table 2. It appears that the IDEW have better performances in both label bit-rate and bit errors. The IDEW algorithm could get a double label bit-rate, but introduces fewer bit errors.

We test the watermark robustness by reencoding the watermarked stream at a lower bit rate and measuring the Bit Errors of the watermark. The sequence is encoded at 1.148 Mbit/s and watermarked. Hereafter, the watermarked video sequence is transcoded at different lower bit rates. The bit errors introduced by decreasing the bit-rate are represented in Figure 5. Although having a double label bit-rate of the DEW algorithm, the IDEW algorithm performs much better on robustness. If the video bit-rate is decreased to 833 Kbit/s, about 17% label bit errors are introduced by DEW, while only 10.8% by IDEW. As the bit-rate decreases, the gap between bit errors introduced by DEW and that by IDEW widens more. As the bit-rate decreases below 667 Kbit/s, the DEW algorithm could hardly extract the label bits.

Table 1. Time-averaged PSNR, percentage label bit errors and label bit-rate for "flower-garden" coded at 1.148Mbit/s, when Number of blocks per bit is set different value.

n	*T-Av. PSNR*		% Bit errors		Label bit-rate(kbit/s)
	IDEW	DEW	IDEW	DEW	
4	30.78	30.26	0	40.00	0.656
8	34.08	33.39	2.42	6.97	0.328
16	37.52	35.25	0	4.85	0.164
32	38.13	37.45	0	0	0.082
64	39.81	38.76	0	0	0.040
128	39.94	38.65	0	0	0.020

Table 2. Number of blocks per bit, number of bits discarded by the watermarking process, percentage label bit errors and label bit-rate for the sequence coded at different bit-rates. Watermarked using the IDEW algorithm and the DEW algorithm

Video bit-rate (kbit/s)	*n*		Discarded bits(kbit/s)		% Bit errors		Label bit-rate(kbit/s)	
	IDEW	DEW	IDEW	DEW	IDEW	DEW	IDEW	DEW
174	32	32	2.2	5.8	0.0	41.5	0.082	0.082
261	32	32	3.2	9.0	0.0	21.9	0.082	0.082
366	32	32	6.4	14.2	0.0	2.4	0.082	0.082
	16	32	6.6	14.2	1.22	2.4	0.164	0.082
630	16	32	17.8	25.4	0.0	0.0	0.164	0.082
1148	16	32	8.6	8.8	0.0	0.0	0.164	0.082

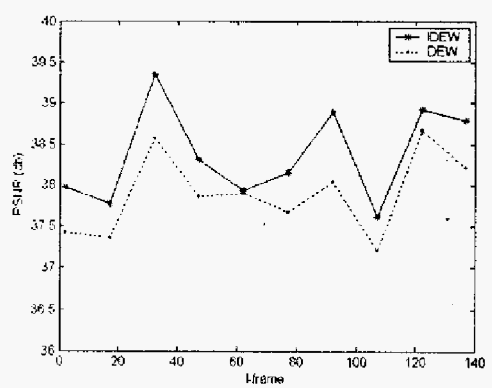

Figure 4. PSNR of first 10 I-frames in watermarked "flower-garden" video

4. Conclusion

In our work, two measures are proposed to improve the DEW algorithm's performance. We have presented the results of our investigation on the performance of the improved algorithm and the original DEW algorithm in three performance criteria, namely payload, robustness and visual quality. Based on these results we can draw the conclusion that the improved algorithm performs better on watermark's visual quality impact, capacity and robustness than the DEW algorithm.

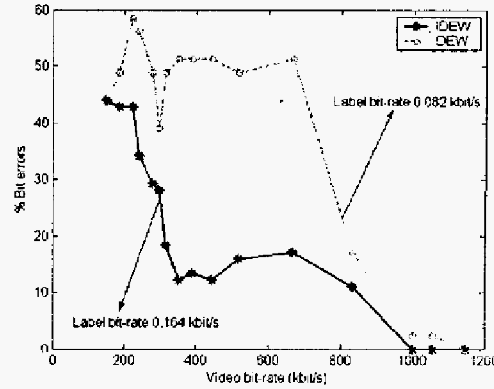

Figure 5. Bit errors after transcoding a watermarked 1.148 Mbit/s "flower-garden" video sequence at a lower bit-rate, watermarked using the IDEW algorithm and the DEW algorithm.

References

[1] Gwenael Doerr and Jean-Luc Dugelay, "A guide tour of video watermarking", Signal Processing: Image Communication, 18 (2003), pp. 263-282.

[2] T.L. Wu, S.F. Wu, "Selective encryption and watermarking of MPEG video", International Conference on Image Science, Systems, and Technology, CISST'97, June 1997.

[3] F. Hartung and B. Girod, "Digital Watermarking of MPEG-2 Coded Video in the Bitstream Domain", Proceedings ICASSP 97, Volume 4, pp. 2621-2624, Munich, Germany, 21-24 April 1997.

[4] F. Hartung and B. Girod, "Copyright Protection in Video Delivery Networks by Watermarking of Pre-Compressed Video", in: S. Fdida, M. Morganti (eds.), "Multimedia Applications, Services and Techniques - ECMAST '97", Springer Lecture Notes in Computer Science, Vol. 1242, pp. 423-436, Springer, Heidelberg, 1997.

[5] F. Hartung and B. Girod, "Watermarking of Uncompressed and Compressed Video", Signal Processing, Vol. 66, No. 3, 1998, pp. 283-301.

[6] G.C. Langelaar, R.L. Lagendijk, J. Biemond "Real-time Labeling Methods for MPEG Compressed Video", 18th Symposium on Information Theory in the Benelux, Veldhoven, The Netherlands, 15-16 May 1997.

[7] G.C. Langelaar, R.L. Lagendijk, J. Biemond, "Real-time Labeling of MPEG-2 Compressed Video", Journal of Visual Communication and Image Representation, Vol 9, No 4, December 1998, pp.256-270.

[8] Chun-Shien Lu, Jan-Ru Chen, Hong-Yuan Mark Liao, and Kuo-Chin Fan, "Real-Time Compressed Video Watermarking in the VLC Domain", Proc. 14th IPPR Conf. on CVGIP, Taiwan, 2001.

[9] G.C. Langelaar, R.L. Lagendijk, "Optimal Differential Energy Watermarking (DEW) of DCT Encoded Images and Video", IEEE Transactions on Image Processing, Vol.10, No. 1, January 2001, pp. 148-158.