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NEW REAL-TIME WATERMARKING ALGORITHM FOR COMPRESSED VIDEO IN VLC DOMAIN

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ABSTRACT

As a main method for copyright protection of digital video data, video watermarking has been proposed and investigated. However, unlike still image, video watermarking technology must meet the real-time requirement. In this paper a new real-time watermarking, differential number watermarking (DNW), which can be directly performed in the VLC domain, will be proposed. The label bits are embedded in a pattern of number differences between two subregions by selectively removing high frequency components. The DNW algorithm has only half the complexity of other VLC domain watermarking algorithms. And comparing with the DEW algorithm, it doesn't need quantization step. The experimental results show that the DNW algorithm performs better on watermark's visual quality impact, capacity and robustness than the DEW algorithm.

1. INTRODUCTION

Digital watermarking has been proposed to be a very useful technology in the protection of digital data such as image, audio, video, formatted documents (PDF or PS), and 3D objects. The research has focused on still images for a long time but nowadays this trend seems to be changing. More and more watermarking algorithms are proposed for other multimedia data and in particular for video content. New application brings up new challenges. Video watermarking should meet some additional specific requirements, such as real-time [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, which can 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 [3,4,5,6], low payload, less robustness [7,8,9,10] and visual artifacts [2] etc. Although the differential energy watermarking (DEW) algorithm proposed by Langelaar *et al* has been shown to have relatively low complexity, high capacity and low visual impact [7,9], it has some disadvantages, which will be discussed in Section 2.1.

In this paper a compressed-domain video watermarking method, which can be directly performed in the VLC domain, will be proposed. Only the inverse entropy coding and tuple coding need to be performed in the watermarking method. Not only the luminance but also the texture of an I-frame should be considered. The differential number of nonzero components in two subregions is used as pattern instead of the differential energy to embed label bits.

This paper is organized as follows. In Sec. 2, the disadvantages of DEW algorithm is briefly introduced and the new scheme is proposed. In Sec. 3, the experimental results are presented. In Sec. 4, the conclusions are drawn.

2. DIFFERENTIAL NUMBER ALGORITHM

2.1. The disadvantages of DEW algorithm

Although the DEW algorithm has relatively low complexity, it has several disadvantages.

Firstly it needs to calculate the energy of many subregions, so it really works in the coefficient domain [10], which increases the complexity. The embedding process on the coefficient domain needs to perform VLC coding, tuple coding and quantization steps.

Secondly it doesn't consider the texture and edge's effect on Human Visual System. As described by Setyawan et al [10], if too many high-frequency components are removed in order to enforce the energy difference, the watermarking artifacts will be visible. Although a randomly shuffled process is done to avoid having a group of blocks where unbalanced energy content exists, the high frequency components still face to be removed.

Thirdly the embedding energy difference D and extraction energy difference D' are chosen only once by *t(r,l)*

VCL (0,5)	VCL (0,3)	VCL (0,2)	VCL (2,4)	VCL (1,7)	VCL (3,2)	VCL (3,1)	VCL (2,4)	VCL (4,1)	EOB

t'(f,l) ⇓ $f_{i+1} = f_i + r_{i+1} + 1,\ f_0 = 0$

VCL (0,5)	VCL (1,3)	VCL (2,2)	VCL (5,4)	VCL (7,7)	VCL (11,2)	VCL (15,1)	VCL (18,4)	VCL (23,1)	EOB

Fig. 1. Transform from *run* to *frequency*

experience (i.e., needs many experiments test) and never change in spite of any hostile or nonhostile attack. This can induce more bit errors. For example, if the reencoding attack happens, some AC-coefficients at high frequency are quantized to zero. However 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.

2.2. Concepts of Differential Number algorithm

In *VLC* domain a block consists of a group of tuples *t(r, l)*. In order to describe the new algorithm, the tuples are represented by *t'(f, l)*, where *f* is the frequency in a zigzag scan. This process is illustrated in Fig. 1.

A watermark consisting of l label bits b_j ($j = 0, 1, 2,\ldots, l-1$) is embedded in the I-frames of an MPEG video stream. Each bit b_j is hidden in a block-region (label-bit-carrying-region, *lc-region*), which consists of n luminance blocks. An *lc-region* is divided into a pair of subregions, one is named A-subregion, and the other is named B-subregion. A label bit is embedded in an lc-region by introducing a number difference D of tuples at high frequency between A-subregion and B-subregion. The particular subset of blocks in this lc-subregion is denoted by $S(c)$, where the frequency of tuples is higher than c or equals to c (i.e., $f \geq c$). The subset is illustrated in Fig. 2 by the white rectangularly shaped areas in the tuples. We define the total Number in $S(c)$, computed over the $n/2$ blocks in *subregion A*, as:

$$N_A(c,n) = \sum_{i=1}^{n/2} n_i \qquad (1)$$

where n_i denotes the number of tuples in the subset $S(c)$ of the i-th blocks. The Number in B-subregion, denoted by N_B, is defined similarly. $S(c)$ is typically defined according to a *cut-off index* c in the group of transformed tuples, so that:

$$S(c) = \{f \in \{1,63\} \mid (f \geq c)\} \qquad (2)$$

The Number difference D between A-subregion and B-subregion is defined as:

$$D = N_A(c,n) - N_B(c,n) \qquad (3)$$

The complete procedure to calculate the number difference D of an lc-region *(n=16)* is graphically illustrated in Fig. 2.

Choosing a value T as threshold, we define the label bit value as the relation between the number difference and threshold T. Label bit "1" is defined as D≥T and label bit "0" as D<(-T). When the watermark bits are embedded, the N_A and N_B must be adapted to satisfy the inequality ($D \geq T$ or $D < (-T)$). The number difference D can be manipulated by selectively removing high frequency components from the blocks. This can be easily done without re-encoding the bit stream by shifting the end of block marker (EOB) of blocks toward the lower frequency component, up to the selected cutoff index. For example if label bit "1" must be embedded and the inequality $D \geq T$ isn't true, we can enforce the number difference N_B to be zero by eliminating all the components of B-subregion after the *cut-off index c*, so that:

$$D = N_A - N_B = N_A - 0 = N_A \geq T \qquad (4)$$

If label bit "0" must be embedded and the inequality $D < (-T)$ isn't true, then eliminates all the components of A-subregion after the cut-off index c, so that:

$$D = N_A - N_B = 0 - N_B = -N_B < (-T) \qquad (5)$$

The procedure to calculate N in a single block and to change N by removing components located at the end of the zigzag scan is graphically illustrated in Fig. 3. The label bits are embedded in a pattern of Number differences between two subregions. For this reason, we call our technique differential number watermark (DNW).

As we know, the characteristics including texture, edges and the quality can result in different number of nonzero DCT-coefficients. So we take the total number of nonzero components in an lc-region into account. We define the Embedding Number Difference Ratio as *ENDR*, so that

$$ENDR = \frac{D}{N_A(0,n) + N_B(0,n)} \qquad (6)$$

where n represents the number of the blocks in an lc-region. *ENDR* represents what percentage of the removed number of nonzero components in an lc-region. Using *ENDR* as evaluation criteria to discard the high-frequency components can lessen the affection of the characteristics.

It has several reasons to use the differential number as pattern instead of the differential energy. The most important reason is that the number difference is much easier to calculate than the energy difference. The calculation of the number difference between two subregions doesn't need to know the value of DCT-coefficients, and it only needs to calculate how many components are in the subregion, which could lower the complexity. Next is that adapting the threshold T can easily consider the texture and edge's effect on visual observation in a region. The threshold T is self-adapted in proportion to the total number of components in a region, which could decrease the bit errors.

Just as described in [7], watermarking bits by removing coefficients has two advantages. Since no coefficients are adapted or added to the stream, the

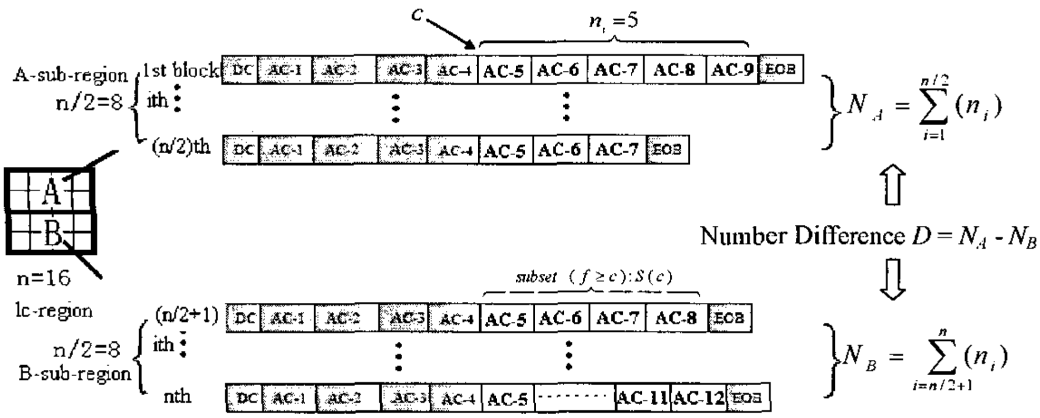

Fig. 2. Number definitions in an lc-region of n=16 8x8 blocks.

embedding process doesn't need re-encoding the bit stream. The watermarking concept can be illustrated in Fig. 4, which shows the difference between the standard VLC domain watermarking and the DNW algorithm, and the difference between DEW and DNW. This means that the DNW algorithm has only half the complexity of other VLC domain watermarking algorithms. And comparing with DEW, it doesn't need quantization steps. Furthermore, removing components will always make the watermark compressed video smaller in size than the unwatermarked video stream. If it is necessary that the watermarked compressed video stream keeps its original size, stuffing bits can be inserted in the video stream.

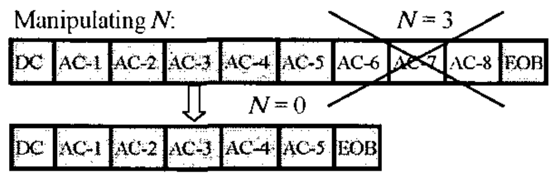

Fig. 3. Adapting Number in an 8x8 compressed block

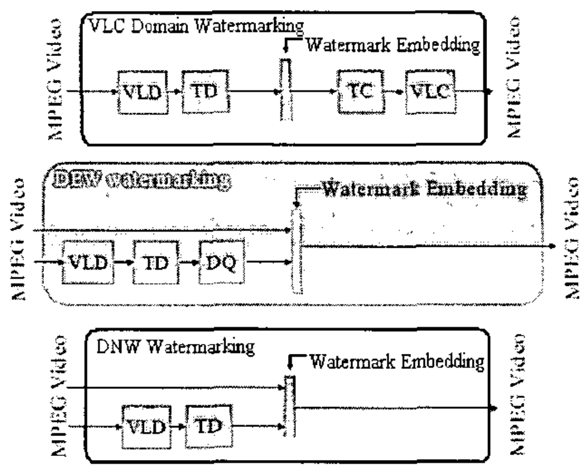

Fig. 4. Complexity difference between the DNW algorithm and the DEW algorithm, other VLC domain watermarking algorithms

3. EXPERIMENT AND DISCUSSION

We test the DNW algorithm to see its performance in terms of watermark's visual quality impact, capacity and robustness. To compare with the DEW algorithm, the "sheep-sequence" video sequence, which has been used in the DEW algorithm, is used as test sequence. For both algorithms, the minimal cut-off point is set at 6 (i.e., C_{min}=6). And for the DEW algorithm, the embedding enforced energy difference is set at 20 (i.e., D=20) and the extraction enforced energy difference is set at 15 (i.e., D'=15). While for the DNW algorithm, the embedding number difference ratio is set at 0.1 (i.e., *ENNR*=0.1) and the extraction number difference ratio is set at 0.03 (i.e., *ENNR'*=0.03).

The visual quality is assessed by calculating the time-averaged *PSNR* value. To evaluate the effect of *ENDR* on the visual quality of the video stream we applied the DNW algorithm to the "sheep-sequence" at different *ENDR*. The experimental results are presented in Table 1. It appears that *PSNR* decreases as *ENDR* increases. In the following experiments, we set *ENDR* at 0.1. It results in a relative high average PSNR (about 38.45db), while with the DEW algorithm (D=20, C_{min}=6, D'=15) it can only attain a low *PSNR* value (about 37db) [7].

The watermark capacity is determined by the number of 8×8 blocks that are used to embed one watermark 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. To compare with the DEW algorithm, we applied the DNW algorithm to the sequence coded at different bit-rates. The results are listed in Table 2. It appears that the DNW algorithm has better performance in both label bit-rate and

Table 1. Time-averaged PSNR, percentage bit errors for "sheep-sequence" coded at 8Mbit/s, when ENDR is set different value.

ENDR	Time-averaged PSNR (db)	% Bit errors
0.30	33.51	0.0
0.27	34.07	0.0
0.24	34.24	0.0
0.21	35.27	0.0
0.18	35.57	0.0
0.15	36.92	0.0
0.12	37.79	0.0
0.09	38.71	0.0
0.06	40.58	0.0
0.03	42.37	0.0

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

Video bit-rate (Mbit/s)	n		Discarded bits (kbit/s)		% Bit errors		Label bit-rate (kbit/s)	
	DNW	DEW	DNW	DEW	DNW	DEW	DNW	DEW
1.4	32	64	5.3	1.6	3.91	24.6	0.42	0.21
2.0	32	64	5.5	4.6	1.56	0.1	0.42	0.21
4.0	32	64	6.1	3.8	0.0	0.0	0.42	0.21
6.0	16	32	6.9	7.2	0.0	0.0	0.84	0.42
8.0	16	32	9.9	6.6	0.0	0.0	0.84	0.42

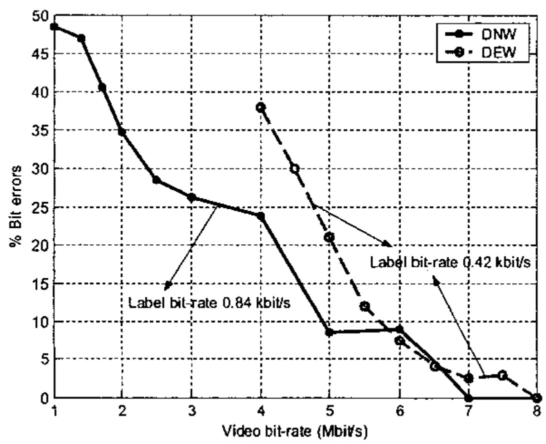

Fig. 5. Bit errors after transcoding a watermarked 8Mbit/s sequence at a lower bit-rate, watermarked using the DNW and DNW algorithm.

bit errors. The DNW 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 8 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 Fig. 5. It appears that the DNW algorithm performs much better than the DEW algorithm. If the video bit-rate is decreased to 4 Mbit/s, about 38% label bit errors are introduced by DEW, while only 24% by DNW. As the bit-rate decreases, the gap between bit errors introduced by the DEW algorithm and that by the DNW algorithm widens more.

4. CONCLUSION

In our work, a new real-time watermarking scheme, DNW, has been proposed based on enforcing Number difference between two subregions. Based on these experimental results we can make the following conclusions:

1) The DNW algorithm has a lower complexity than the DEW algorithm and other VLC domain algorithms.
2) The DNW algorithm performs better on watermark's visual quality impact, capacity and robustness than the DEW algorithm.
3) For the DNW algorithm, it is very important to choose the value of embedding number difference ratio *ENDR* and extraction number difference ratio $ENDR'$. The principle for choosing these determined parameters needs to be further investigated.

REFERENCES

[1] A 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 and 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, "Watermarking of MPEG-2 Encoded Video Without Decoding and Re-encoding," *Proceedings Multimedia Computing and Networking 1997(MMCN 97)*, San Jose, CA, February 1997.

[4] 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, April 1997.

[5] F. Hartung and B. Girod, "Copyright Protection in Video Delivery Networks by Watermarking of Pre-Compressed Video," *Springer Lecture Notes in Computer Science*, Vol. 1242, pp. 423-436, Springer, Heidelberg, 1997.

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

[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, pp.256-270, December 1998.

[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, pp. 148-158, January 2001.

[10] I.Setyawan, R.L.Lagendijk, "Extended Differential Energy Watermarking (XDEW) Algorithm for Low Bit-rate Video Watermarking," *in the Proceedings of the Seventh Annual Conference of the Advanced School in Computing and Imaging*, Heijen, The Netherlands, pp. 202-209, 2001.