Data Hiding of Motion Information in Chroma and Luma Samples for Video Compression

Jean-Marc Thiesse, Joël Jung, Marc Antonini

Data hiding of Motion Information in Chroma and Luma Samples for Video Compression

Jean-Marc Thiesse #1, Joël Jung #2, Marc Antonini *3

Orange Labs

38 rue du G. Leclerc, 92794 Issy les Moulineaux, France

{1 jeanmarc.thiesse, 2 joelb.jung}@orange-ftgroup.com

* I3S Lab. University of Nice-Sophia Antipolis/CNRS

2000 route des Lucioles, 06903 Sophia Antipolis, France

3 am@i3s.unice.fr

***Abstract*—2010 appears to be the launching date for new compression activities intended to challenge the current video compression standard H.264/AVC. Several improvements of this standard are already known like competition-based motion vector prediction. However the targeted 50% bitrate saving for equivalent quality is not yet achieved.**

In this context, this paper proposes to reduce the signaling information resulting from this vector competition, by using data hiding techniques. As data hiding and video compression traditionally have contradictory goals, a study of data hiding is first performed. Then, an efficient way of using data hiding for video compression is proposed. The main idea is to hide the indices into appropriately selected chroma and luma transform coefficients. To minimize the prediction errors, the modification is performed via a rate-distortion optimization.

Objective improvements (up to 2.3% bitrate saving) and subjective assess

ment of chroma loss are reported and analyzed for several sequences.

I. Introduction

Significant compression gain, compared to former video coding standards, has been achieved by the H.264/AVC standard [1] resulting from the joint work of the ITU-T SG16-Q6 and ISO/IEC Moving Pictures Experts Group (MPEG). This gain results from the improvement of existing tools and the inclusion of new ones. These improvements concern the motion estimation, the information coding with Context Adaptive Binary Arithmetic Coding (CABAC), and above all the addition of several Intra and Inter modes with many encoding methods which need the transmission of competition signalization indices.

Today, after the MPEG Call for Evidence, both VCEG (Video Coding Expert Group) and MPEG have issued a Call for Proposals, with answers expected in April 2010. The goal is to reach a video coding standard that provides a bitrate reduction of 50% at the same subjective quality, with an allowed increase of the complexity by a factor 2 or 3. Several improvements are already known and gathered in the JM KTA software (Key Technical Area) [2]. However the targeted bitrate saving is not yet achieved. Among these improvements, some contributions add new competition indices which are more and more costly. This paper proposes a way for reducing this cost with a framework that allows to hide such indices in chroma and luma texture samples.

The remaining of this paper is organized as follows: an H.264/AVC and data hiding state of the art is presented in Section 2. Section 3 introduces our proposed index hiding scheme after a preliminary study. Finally the experimental results are reported and analyzed in Section 4.

II. State of the art

A. H.264/AVC and latest KTA improvements

1) H.264/AVC prediction and coding: H.264/AVC is an hybrid video coder: Intra and Inter prediction are used together to exploit spatial and temporal redundancies. For each macroblock, several modes are in competition and need to be signaled to the decoder with other information of residual or coding type (submode, DCT size,...).

All of them are stored sequentially in the bitstream and moreover independently one from the other. In order to reduce this cost, a Most Probable Mode is used: the mode that is the most probable is encoded with 1 bit only. Although context adaptive encoding is performed, the cost with these existing methods remains high. At medium bitrate, the competition information represents 20% of the total bitrate and this proportion increases to 40% for lower bitrates.

In this paper, we propose to use data hiding for decreasing the rate cost of these competition indices. In particular, we choose to deal with the motion information index generated by the Motion Vector Competition (MVComp) tool.

2) Motion Vector Competition overview: The MVComp tool [3] has been integrated in the JM KTA for improving H.264/AVC. In order to improve the motion vector prediction this tool proposes a competing framework which optimally selects the predictors in competition by a rate-distortion criterion.

However this scheme requires the transmission of indices for signaling the selected predictor. Thus, the rate R_{mv_i}

MMSP'10, October 4-6, 2010, Saint-Malo, France.
978-1-4244-8112-5/10/$26.00 ©2010 IEEE.

generated by the motion information coding of the motion vector mv for the motion vector predictor $p_i, \forall i \in \{1, ..., n\}$ is equal to:

$$R_{mv_i} = \varsigma(\varepsilon_{mv_i}) + \varsigma(i), \quad (1)$$

where $\varsigma(x)$ is the rate cost of the data x in the bitstream, i is the index of the predictor p_i, and ε_{mv_i} is the motion vector residual, defined by:

$$\varepsilon_{mv_i} = mv - p_i. \quad (2)$$

The aim of our work is to reduce the rate cost $\varsigma(i)$ of remaining indices by hiding the predictor index i. For this study, $n = 2$ (the best MVComp configuration) and the index i is consequently binary. More detailed informations on MVComp can be found in [3].

B. Data Hiding

Data hiding and video compression traditionally have contradictory goals. The first one adds imperceptual information to embed data, while the second removes redondant information to reduce video size. This section introduces data hiding.

1) Theory: Data hiding deals with the ability of embeding data into a digital media with a minimum amount of visible degradation. There are many applications of data hiding. For each one, a complex trade-off between three parameters is needed: data playload (amount of informations to hide), fidelity (distortion induced by the mark) and robustness (resistance to attacks).

Three class of data hiding approaches are reported; the first extends still image watermarking and the second exploits the temporal dimension of video in order to increase the fidelity and the robustness. These contributions [4] principally use the spread-spectrum theory: the message is shared over a wide range of frequencies of the host data.

The last classes is based on the characteristics of video compression standard. The most studied topic is to hide informations in the non-zero DCT coefficients of a compressed video stream. Among these approaches, the Force Even Watermarking (FEW) has been proposed in [5]: it hides information in the parity of AC coefficients at the cost of a bitrate increase. After a study of CABAC process, authors propose in [6] to embed watermark bit to the sign of the Trailing Ones. Consequently, the bitrate is not modified but there is a degradation of the visual quality due to error propagation. A solution is proposed in [7] by embedding each bit on the parity sum of the transform coefficients. This approach permits to choose the modification which induced the smallest degradation. Some other contributions deal with hiding in motion vectors, for instance by modifying their parity [8].

2) Video compression using data hiding: Only a few methods propose to use data hiding for compression, as in our paper. The notion of compressive data hiding has been formalized in [9]. Authors propose to exploit data hiding to improve coding efficiency by hiding the chrominance information in the wavelet domain of the luminance component before image compression. A similar scheme is proposed in [10] using DCT instead of wavelet transform in order to embed the color information in a JPEG grey level image. In [11], the signal to be compressed is split into a host image part and a residue image part. Only the host portion needs to be compressed after embedding of the residue part.

These approaches confirm that using data hiding methods for compression can be interesting.

III. Proposed method for Data hiding of motion information

A. Preliminary study

We first study some of the data hiding techniques introduced in section 2 in order to choose where some data could be hidden and what kind of data could be used.

We have privilegiated schemes which embed the mark directly into the compressed video stream, especially into the pixel residuals. Among all the contributions, it is the hiding in the parity of the sum of the transform coefficients which is the most appropriate for this work because it permits to easily balance between rate and distortion modification.

Among the competition index, we have selected to mark the one generated by the MVComp tool for increasing its gains, although this is not proportionately the most expensive (it represents 15% of the motion information bitrate and only 2% of the total bitrate at medium bitrate).

B. Scheme description

We propose to use the Chroma and Luma transform coefficients to hide the MVComp index. This hiding is complex because of the specificities of CABAC and the prediction damages. To solve these problems, the proposed scheme must satisfy the following requirements:

1) Control of the bit-rate change: it must be lower than the index signaling, $R_i^w - R_i < \varsigma(I_i)$, where R_i and R_i^w are the original and the modified rate of the i^{th} block, and $I_i \in \{0, 1\}$ the predictor index with $\varsigma(I_i)$ its cost.
2) Minimization of prediction degradation: the transform coefficients modification must be invisible and must have low impact on the prediction of the next frames.

In order to meet these requirements, we use the parity of the coefficients sum to mark the MVComp index. The first requirement can be met by rejecting all the modifications which increase the original bit-rate too much. For the second requirement, a rate-distortion optimization is applied.

Let us note a_n, $n \in \{1, ..., N\}$ the transform and quantized coefficients before transmission. The sum of the coefficients of the i^{th} block is denoted as S_i:

$$S_i = \sum_{n=1}^{N} a_n. \quad (3)$$

The resulting modified S_i^w is obtained as follow:

$$S_i^w = \begin{cases} S_i & ; |S_i| \, mod \; 2 = I_i \\ S_i + m_i & ; |S_i| \, mod \; 2 \neq I_i, \end{cases} \quad (4)$$

where I_i is the index and m_i is the coefficients shift. For minimizing the luminance impact, the sample for hiding belongs to Chroma if there is any Chroma AC coefficients, to Luma otherwise. In order to limit the prediction degradation, we do not use the blocks whith DC coefficients only.

We propose to use a rate-distortion optimization to choose the best modification in the case where the transform coefficients need to be modified, i.e: $I_i \neq |S_i| \, mod \; 2$.

We consider N transform coefficients a_n, $a_n \neq 0$. For each coefficient, 6 rate-distortion couples $(R_n^{w_j}, D_n^{w_j})$, are computed after addition of an odd value m_j:

$$a_n^{w_j} = a_n + m_j. \tag{5}$$

We choose to limit the m_j values to $\{-5, -3, -1, 1, 3, 5\}$ because larger ones induce too high signal modification. $R_n^{w_j}$ is the rate generated by the coding of the transform coefficients after modification and $D_n^{w_j}$ is the related distortion. The transform coefficients equal to zero are not considered to avoid breaking the zero series.

In order to select the modification couple (a_n, m_j) which gives the best compromise, a rate-distortion optimization is proposed with the minimization of the following criterion:

$$J_n^{w_j} = D_n^{w_j} + \lambda R_n^{w_j}, \tag{6}$$

where $(R_n^{w_j}, D_n^{w_j})$ is the couple defined above and λ is the Lagrangian multiplier.

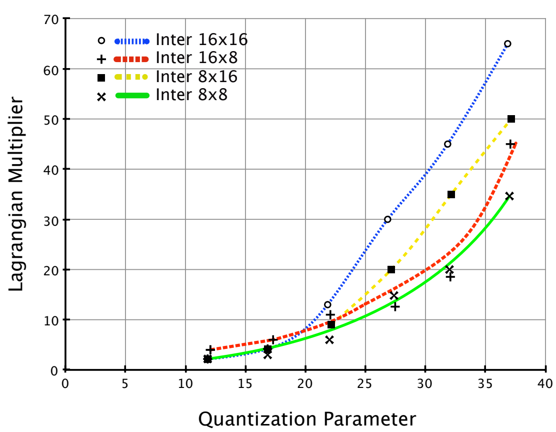


Figure 1. Lagrangian multiplier values determined for each QPs, for the mode 16x16 to 8x8 in the case of Luma modification.

The Lagrangian multiplier values have been empirically determined for each Inter mode in Chroma and Luma, using the λ determined from 5 CIF sequences, for 7 representative QPs. Corresponding curves for different Inter modes are shown in Figure 1, and (7) shows the expression for Inter 16×16, with $\gamma = 4.8$ for Chroma and $\gamma = 1.4$ for Luma. Note that the multiplier selected gives more importance to the distortion for the luminance component.

$$\lambda_{16\times16}(QP) = \gamma \times 2^{\frac{QP-12}{3}} \tag{7}$$

The index extraction at the decoder side is expressed as:

$$I_i = |S_i| \, mod \; 2, \tag{8}$$

where I_i represents the extracted index of the i^{th} block and S_i is the sum of the decoded transform coefficients a_n, if there is at least one non zero AC coefficient. The MVComp index is set to I_i. If there is no AC coefficient transmitted, the MVComp index is traditionally read.

IV. Objective Evaluation

A. Experimental settings

The proposed scheme has been implemented into the JM KTA software [2] version 2.1. H.264/AVC reference results are generated using Intra, Skip and Inter modes from 16×16 to 8×8. The 4×4 DCT transform is enabled and CABAC entropy coding method is selected. The sequences are encoded with the High profile, IPPP encoding configuration.

Experiments have been performed on 8 sequences, with resolutions from CIF to 1080p. Two ranges of Quantization Parameters (QP) have been selected to study the results from high to medium bitrates: QP set 1: 12-17-22-27, QP set 2: 22-27-32-37. All bitrate savings are computed on PSNR-Y with the Bjontegaard metric [12] as recommended by VCEG.

B. Experimental Results

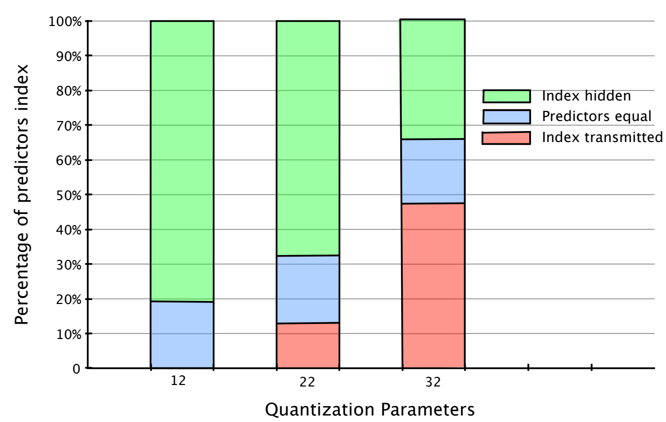


Figure 2. Percentage of index transmitted or not transmitted due to the equality test and the index hidden for 3 QPs.

Figure 2 gives the percentage of index transmitted and those which are not transmitted thanks to either the predictors equality or the index hiding. The proportion of equal predictors remains constant for each QP. We can note that there is no index transmission needed at high bitrate and less than 50% for Qp=32. The proposed scheme is particularly efficient at high bitrate with 80% of index hidden. In fact the ratio between coefficients availables and number of MVComp index to transmit is better at high bitrate, especially in Chroma samples. The proposed scheme achieves expected performance especially at high bitrate, and allows a significant motion information reduction of 20% in average.

QP range	Set 1	Set 2
Bbc_news CIF	2.26	1.37
Schumacher CIF	0.93	0.51
Drama CIF	1.65	-0.10
News_car CIF	1.93	1.24
Rugby CIF	1.18	0.49
Keiba3 WVGA	0.74	0.48
Crowdrun 720p	0.84	0.36
Crowdrun 1080p	0.71	0.27
Average	**1.28**	**0.58**

Table I
PERCENTAGE BITRATE SAVINGS FOR THE TWO SET OF QPS.

About the overall gain, table Igives the percentage bitrate savings for each sequence for the 2 ranges of QPs. This gain remains low, yet non negligible, due to the low proportion of the MVComp index on the total bitrate. The proposed scheme gives a systematic bitrate saving for all sequences except for *Drama CIF*. The best results are obtained for *Bbc_new CIF* and *News-car CIF* sequences which reach 2.26% and 1.93% bitrate savings. Indeed, these sequences have a lot of chroma coefficients availables and consequently the scheme has low impact on the Luma prediction. As expected in figure 2, the results according to the QP range are better for the high bitrate with 1.28% in average.

QP	12	22	32
Chroma DC	5	7	3
Chroma AC	83	44	17
Luma	12	49	80

Table II
PERCENTAGE OF EACH MODIFIED SAMPLES FOR 3 QPS.

Table II gives the percentage of each sample hiding for three QPs. Indices are hidden mainly in the Chroma at high bitrate whereas the Luma plays the most important role at low bitrate. This is an important result of this study, confirming that the scheme efficiency is closely related to the amount of chroma samples available, and also that hiding in the luma requires carefulness to avoid prediction error propagation in the next frames.

V. SUBJECTIVE EVALUATION

A. Observation

	Chroma U		Chroma V	
QP range	**Set 1**	**Set 2**	**Set 1**	**Set 2**
Bbc_news CIF	-0.12	-0.01	-0.20	-0.11
Schumacher CIF	-0.06	-0.05	-0.16	-0.08
Drama CIF	-0.20	-0.07	-0.12	-0.02
News_car CIF	-0.13	-0.06	-0.08	-0.02
Rugby CIF	-0.22	-0.08	-0.16	-0.07
Keiba3 WVGA	-0.11	-0.05	-0.07	-0.03
Crowdrun 720p	-0.17	-0.08	-0.17	-0.10
Crowdrun 1080p	-0.15	-0.06	-0.13	-0.03
Average	**-0.14**	**-0.05**	**-0.13**	**-0.05**

Table III
DELTA-PSNR OF THE CHROMA U AND CHROMA V COMPONENTS FOR THE PROPOSED SCHEME COMPARED TO THE REFERENCE.

Table III gives the average delta-PSNR relative to the U and V chroma components for the proposed scheme compared to the reference for two sets of QPs. As expected, the proposed scheme gives a systematic loss for all sequences. The losses are equivalent in average for the two components, confirming the equivalent repartitions of the mark. The losses increase of 0.1% in average at high bitrate (QPs set 1) compared to medium bitrate (QPs set 2). It is explained by the high number of coefficients modified at high bitrate as shown in figure 2. Finally, we can note that ones of the worst results correspond to the sequences with the higher gain in table I, it is notably the case for *Bbc_news CIF* and *Drama CIF*.

This objective degradation of the chroma is a natural consequence of the proposed method. The most important question now is to know if this degradation is perceived by the human observer. For that purpose, subjective testing have been performed.

B. Experimental Protocol

Subjective evaluation is an experimental method intended to find changes in perceived quality. Tests were design for Double Stimulus Improvement Scale (DSIS). Each test consists of a pair of stimuli, including the reference and the sequence coded with the proposed method, displayed in a random order. Five of the sequences with the highest objective chroma loss (table III) have been displayed two times: the first test is for an overall assessment and the second is for an assessment focused on the color quality. In other words, viewers are explicitly asked to concentrate on chroma distortions. Figure 3 shows the scales for quality scoring.

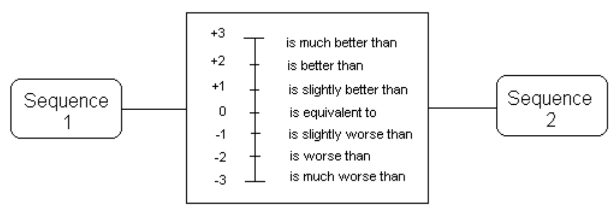
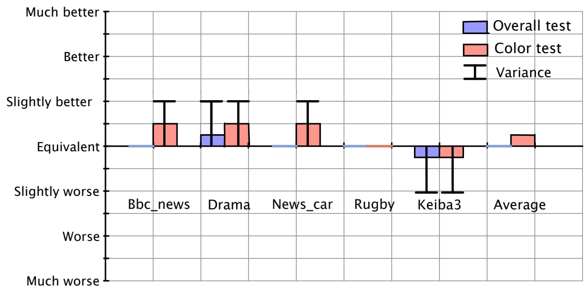


Figure 3. Scale for comparative quality scoring.

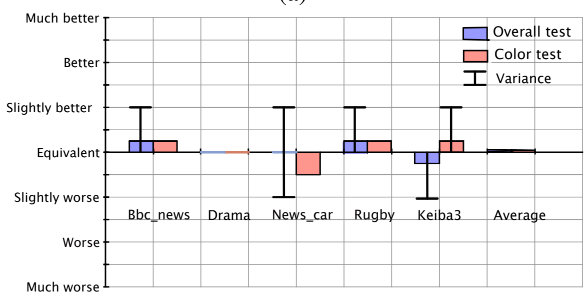
A combination of evaluation by four viewers is used. Finally, the Mean Opinion Score (MOS) is computed for each sequence. Viewers are asked to rate the processed video acording to the common recommendations.

C. Interpretation

Figure 4 gives the results obtained for each sequences for the two test phases, the results are also given for high bitrate (a) and medium bitrate (b). The major conclusion is that the sequence quality (overall and color) is not visually affected by the proposed scheme. In fact, none viewer scores a test with a scale superior to one ("slightly better than"). Consequently, the visual damages can be considered as invisible. However, we can notice that the impact is more perceived at high bitrate than at medium bitrate, and confirms the results observed in section V-A. Some viewers have also better scored the sequence encoded with the proposed scheme, in particuler *Keiba3*, confirming that the sequences are very close. Finally, the modification of the quality is more perceived for the second test where the viewers have been asked to focus on color degradation but it remains low.



(a)



(b)

Figure 4. MOS for each tested sequence at high (a) and medium (b) bitrate. Comparison of the reference with the proposed scheme.

As an example, figure 5 presents the *Bbc_news CIF* sequence which provides one of the highest loss. The figure shows the sequence compressed with the reference software (a), compressed with the proposed scheme (b) and the difference between these two sequences.

(a)

(b)

(c)

Figure 5. The *Bbc_news CIF* sequence: (a) Compressed with the reference software, (b) Compressed with the index hiding on chroma component, (c) Difference between (a) and (b).

VI. Conclusion

In this paper, an unconventional application of data hiding is presented: it is used to perform video compression. After a preliminary study of data hiding schemes, a solution for hiding index generated by motion information in chroma and luma samples is proposed. The indices have been hidden into the transform coefficients through a rate-distortion optimization in order to minimize the damages on the prediction.

Main issues of the proposed approach have been highlighted and solved, in particular the amount of data to hide, the mark location, and the strength of coefficient alteration, to achieve good compromise between bits saving, prediction error propagation in luma texture, and visual aspect on chroma.

The reported results are low with 1.3% in average but non negligible (up to 2.3%). This is directly related to the index proportion in the total bitrate which is also low (2% in average). However, the expected goal is achieved with 50% of non transmitted index in average and a reduction of the motion information of 20%. The proposed method consequently appears as a nice and efficient way to reduce the cost of other more costly indices. As another perspective, the proposed method is expected to provide large gains on 4:4:4 sequences.

References

[1] "Advanced Video Coding for Generic Audiovisual Services, ITU-T Recommendation H.264 and ISO/IEC 14496-10 (MPEG-4 AVC)," Standard Version 7: Apr. 2007, ITU-T and ISO/IEC JTC 1.

[2] K. Suehring, "H.264/AVC and KTA software coordination." Available: http://iphome.hhi.de/suehring/.

[3] G. Laroche, J. Jung, and B. Pesquet-Popescu, "RD optimized coding for motion vector predictor selection," IEEE Trans. on CSVT, 18(9) :1247-1257, Sep. 2008.

[4] F. Hartung and B. Girod, "Watermarking of Uncompressed ans Compressed Video", in Sig. Proc., 66(3):283-301,1998.

[5] O.Nemethova, G. Calvar Forte, and M.Rupp, "Robust Error Detection for H.264/AVC Using Relation Based Fragile Watermarking," IWSSIP, Budapest, Hungary, Sep. 2006.

[6] S. M. Kim, S. B. Kim, Y. Hong, and C. S. Won, "Data Hiding on H.264/AVC Compressed Video," ICIAR, Berlin, 2007.

[7] L. M. Marvel, G. W. Hartwig, C. Boncelet, "Compression Compatible Fragile and Semi-Fragile Tamper Detection," SPIE Int. Conf. on Security and Watermarking of Multimedia Contents II, vol. 3971, USA, 2000.

[8] F. Jordan, M. Kutter, and T. Ebrahimi,"Watermarking technique for hiding/retrieving data in compressed and decompressed video," ISO/IEC JTC1/SC29/WG11, MPEG97, 1997.

[9] P. Campisi, D. Kundur, D. Hatzinakos, and A. Neri, "Compressive Data Hiding: An Unconventional Approach for Improved Color Image Coding," EURASIP JASP, 152-163, 2002.

[10] M. Chaumont, and W. Puech, "A DCT-Based Data-Hiding Method to Embed the Color Information in a JPEG Grey Level Image," EUSIPCO, Italy, Sep. 2006.

[11] B. Zhu, and A. H. Tewfik, "Media Compression via Data Hiding," 31^{st} Asilomar Conf. on SSC, vol. 1, pp. 647-650, 1997.

[12] J. Jung and S. Pateux, "An Excel add-in for computing Bjontegaard metric and its evolution," ITU-T VCEG contribution VCEG-AE07, Marrakech, Jan. 2007.