

Coding Multiple H.264 Video Streams using SSIM as Quality Metric

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Abstract— This paper proposes a joint rate control scheme for multiple video sequences coding based on H.264/AVC standard that produces uniform picture quality. Structural Similarly Information (SSIM), is assessed as a coding complexity of a video program measure regarding its perceptual quality. Initial results are presented and discussed.

Index Terms— Joint video coding, SSIM, video quality, H.264.

I. INTRODUCTION

THE H.264/MPEG-4 Advanced Video Coding standard (H.264/AVC) [1] is the newest video coding standard jointly developed by the ISO/IEC Moving Picture Experts Group (MPEG) and the ITU-T Video Coding Experts Group (VCEG)[1]. H.264/AVC has accomplished a substantial progress regarding coding efficiency regarding its predecessors [2]. It covers common video applications such mobile services or Internet Protocol Television (IPTV) [2].

The combine use of H.264/AVC and statistical multiplexing techniques in broadcast systems provides a service with a higher quality regarding current systems [3]. The joint coding of video sources has become an important part of many digital video broadcast systems. The goal of these systems is to guarantee best possible usage of channel capacity while providing consistent picture quality through the use of automatic bit-rate allocation.

The scientific issues concerning picture quality and joint coding control are rather complex and ongoing research is needed to find which techniques give the best solutions to guarantee the differing requirements within the broadcasting community.

This paper proposes a bit allocation strategy for joint coding of multiple video programs that produces uniform picture quality. A model of program complexity based on Structural Similarly Information (SSIM), which assess the coding

complexity of a video program regarding its perceptual quality. Furthermore, simulation results are present and discuss.

II. VIDEO QUALITY ASSESSMENT

A. Introduction

One of goals in the design of visual communication systems is to represent, broadcast and reproduce the information that the human eye can see and perceive. The most reliable way of assessing the quality of an image or video is subjective evaluation, because human beings are the final receivers in most applications [12], [13]. Nevertheless, subjective evaluation is too complex (wide variety of possible methods and test elements) and provides too much variability in results.

However, since it is the observer's opinion of picture quality that counts, any objective measurement system must have good correlation with subjective results for the same video system and test scenes. To be able to incorporate HVS model into broadcasting encoding system could result in additional improve of the coding efficiency and enhance video quality.

Typically, to measure the video quality we can find, in the literature, metrics such as the Peak signal-to-noise ratio (PSNR) and the Mean Square Error (MSE), Sum of Squared Differences (SSD), Mean Absolute Difference (MAD), and Sum of Absolute Differences (SAD). These metrics can be determined by the following expressions:

$$PSNR = 10 \log_{10} \frac{A^2}{MSE} \quad (1)$$

$$MSE = \frac{1}{HW} SSD \quad (2)$$

$$SSD = \sum_{i=0}^{H-1} \sum_{j=0}^{W-1} (p(i, j) - \hat{p}(i, j))^2 \quad (3)$$

$$MAD = \frac{1}{HW} SAD \quad (4)$$

$$SAD = \sum_{i=0}^{H-1} \sum_{j=0}^{W-1} |p(i, j) - \hat{p}(i, j)| \quad (5)$$

where H and W denote the image dimension (height and

Manuscript received April 15, 2008. This work was supported by "Fundação para a Ciência e Tecnologia" and "Programa Operacional Ciência e Inovação 2010" (POCI 2010), co-funded by the Portuguese Government and European Union by FEDER Program.

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width of the image), A represents the maximum grey level of the image ($A = 255$ for 8-bit representation), and $p(i, j)$ and $\hat{p}(i, j)$ represent the “original” and the processed image pixels at position (i, j) . These metrics have been the target of an high number of critics for not correlating well with HVS [14][15] as they can not signify the exact perceptual quality as they are based on pixel to pixel difference calculation and ignore human perception and the viewing condition. Ongoing work regarding the impact of coding distortion on the subjective quality is still under investigation [16], [17], [18] and [20].

B. Structural Similarity Index (SSIM)

A new scheme for a class of quality metrics, known as Structural Similarity (SSIM), has been proposed to model perception implicitly by taking into account the fact that the Human Visual System (HVS) is adapted for extracting structural information (relative spatial covariance) from images [14]. SSIM is an objective image quality assessment metric which attributes perceptual degradations to structural distortions [19]. The SSIM index has been demonstrated in [13] to be an effective measurement of perceptual global degradations in natural images.

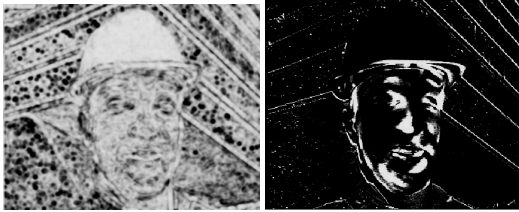


Fig. 1 Example 1 on SSIM Distortion Map versus MAD Distortion Map for CBR 256kbps, frame 1, Foreman sequence: (a) SSIM; (b) MAD

Fig. 1 compares the use of SSIM metric with MAD metric. SSIM provides local perceptual cues of importance that can support towards perceptual visual coding. This is a result of how SSIM has successfully incorporates HVS characteristics without much added complexity. As describe in [13] and [19] SSIM index can be implemented using a set of equations defining SSIM quality metric in image space depending on luminance l , contrast c , and structure s between the reference and the distorted image. Let us consider the reference image as x and the distorted image as y , and then each of these parameters can be determined by the expressions:

$$SSIM(x, y) = l(x, y)^\alpha \cdot c(x, y)^\beta \cdot s(x, y)^\gamma \quad (6)$$

where α, β, γ are positive constants used to weight each comparison function. The comparison functions are given by:

$$\begin{aligned} l(x, y) &= \left(\frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \right), \\ c(x, y) &= \left(\frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2} \right), \\ s(x, y) &= \left(\frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \right) \end{aligned} \quad (7)$$

where C_1, C_2 and C_3 are constants to avoid instability and $\mu_x, \mu_y, \sigma_x, \sigma_y$ are computed as the mean and standard deviation of the reference and distorted image [19], [21], [22].

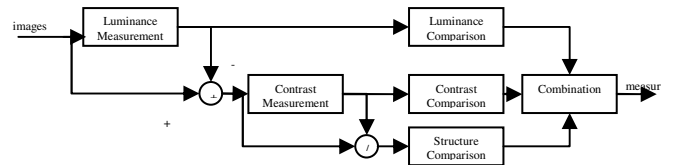


Fig. 2 Diagram of image similarity measurement system.

Fig.2 presents a simple diagram of the SSIM process.

$$SSIM(x, y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (8)$$

In our simulation, we have followed the reference [14] and have selected the following parameters $\alpha = \beta = \gamma = 1$ and $C_3 = C_2/2$ to get the SSIM value.

III. RATE MODELS

Usual, in broadcast systems, multiple video programs are encoded with the same constant bit rate. As the nature of each program differs, for example sports versus news, and its content suffers changes due to scene content varies over time, the resulting video quality is not constant and the difference between the different video programs is not smooth. Therefore, to obtain equivalent video quality for all the broadcast video programs, based on the rate-distortion theory, the allocated channel bandwidth should varies among the programs according to the program content, i.e., complexity of each of the video sources.

Among existing solutions for joint video coding, the rate control of MPEG-2 Test Model 5 (TM5) [5] have been the starting point for most of the proposals in the literature [6], and [7]. The complexity measure of TM5 is determine by

$$X^t = R^t \times Q^t, \quad t = I, P, B \quad (9)$$

where X denotes a complexity measure for each type picture type, R the actual number of bits, Q the quantization parameter, and t the picture type. But TM5 rate control

algorithm, while a good starting point, was designed for MPEG-2, a very different codec than H.264/MPEG-4 AVC. The extensive adoption of the new H.264/AVC video codec standard makes it necessary to study the video encoder's statistical characteristics and compression performance. To best of our knowledge the number of publications on this topic is still very limited [7], [8], [11]. Also a thorough study regarding the application of these methods regarding H.264, including objective and subjective video quality assessment, appears to be missing. Work in this area applied to new codecs has recently started. J. Yang et al. propose in [9], [10] an approach where the mean absolute difference (MAD) of the residual components is used as the complexity measure to adapt to the characteristics of H.264 video coding.

A. Rate-Distortion Model

Previous to present our rate-control technique idea, we first make a study of the quantization scheme and the R-D relation in H.264/AVC. To achieve the target bit rate, the rate control scheme needs to choose the correct quantization parameter. For accuracy, it is of importance to exactly model or estimate the coding bit rate in terms of the quantization parameter, namely rate-quantization ($R-Q$) functions. Together with distortion-quantization ($D-Q$) functions, $R-Q$ functions characterize the rate-distortion ($R-D$) behavior of video encoding, which is the key issue of optimum bit allocation. Many $R-Q$ and $D-Q$ functions have been reported in previous studies [28], and [29] in the literature.

In order to examine the behavior of the coding bit rate R regarding SSIM, we have encoded twelve CIF video sequences, 25 frames per second, with the duration of 10 seconds each (Akiyo, Coastguard, Deadline, Flower Garden, Football, Foreman, Hall, Mobile & Calendar, Mother & Daughter, News, Paris and Silence). We have used the JM reference software (version 10.2) of the H.264/AVC codec [27]. Different temporal prediction structures were simulated with Intra Period varying between of 4 and 10, with two B frames.

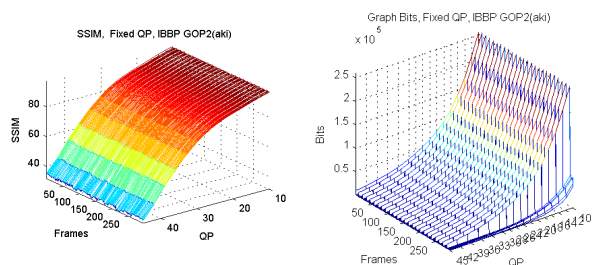


Figure 1. SSIM and bit rate surfaces at various values of QP and frames for the “akiyo_cif” sequence.

GOP Pattern	Intra Period	N° of B Frames	Pattern
IBBP_GOP1	10	2	IBBPBBPBBPBBPBB PBBPBBPBBPBBPBB
IBBP_GOP2	4	2	IBBPBBPBBPBB
IPPP_GOP1	4	0	IPPP
IPPP_GOP2	10	0	IPPPPPPPPP

Table 1 – GOP Patterns

The sequences were encoded 40 times for fixed quantization parameter QP ranging from 5 to 45 (Figure 1). Figure 1 shows that the actual rate R is a decreasing function of the distortion D (a larger QP results in a lower value of picture quality that corresponds to a larger distortion D). Furthermore, the actual R is also an increasing function of SSIM under a fixed quantization parameter, as show in Figure 1. We can summarize the observations regarding bit rate R as the following: 1) the bit-rate R is a decreasing function of the distortion D ; and 2) SSIM is an increasing function of R under a fixed quantization parameter.

To further reveal the relation between R , QP and SSIM we have analyzed results applying curve fitting technique. Before fitting data into a function that models the relationship between two measured quantities, it is a normal procedure to determine if a relationship exists between these quantities. Correlation is a method to confirm the degree of probability that a linear relationship exists between two measured quantities.

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \quad (10)$$

where r is a matrix of correlation coefficients. The sample correlation always lies in the interval from -1 to 1.

Sequence	IBBP-GOP1			IBBP-GOP2		
	I Type	P Type	B Type	I Type	P Type	B Type
aki	0,9017	0,8895	0,9618	0,8975	0,8854	0,9612
fot	0,9738	0,9688	0,9807	0,9687	0,9657	0,9799
new	0,9164	0,8621	0,9111	0,8622	0,8668	0,9131
par	0,9178	0,9143	0,9426	0,9178	0,9137	0,9439
sil	0,9335	0,9287	0,9466	0,9288	0,9283	0,9457

Table 2 - Correlation coefficients between Bits Rate and Quality Metric (SSIM).

A value of r near of positive one or negative one, it is interpreted as indicating a relatively strong linear relationship and r near zero is inferred as indicating a lack of linear relationship. The sign of r indicates whether y tends to increase or decrease with increase x . Results shows a strong correlation between SSIM e Bit Rate.

Fit Method	IBBP GOP2		
	I Type	P Type	B Type
Linear fit	3,20E+08	2,85E+08	3,64E+08
Logarithmic fit	5,82E+08	4,65E+08	8,89E+08
Power Regression	3,17E+08	2,91E+08	3,41E+08
LNP fit	1,39E+09	9,18E+08	2,55E+09

Table 3 - Average Square Error, per frame, in 12 video sequences for Rate-SSIM curve fitting.

Table 3 shows results for curve fitting using Least Squares Methods of Linear Regression Analysis and different fit methods. Simulations in Table 3 are from the twelve video sequences. As mention previously, quantization parameter QP was fixed and simulations were performed for different values between 5 and 45. Results are consistent and linear relation presents the best results. More experimental results on the other GOP patterns also show similar results. As a consequence, we can draw a conclusion that the relation between R and SSIM can be taken as linear in H.264/AVC.

IV. PROPOSED RATE CONTROL

The proposed rate control and complexity measure application are discussed in this section. The Rate Control operate at different levels, specifically, sequence-level, frame level, and macroblock (MB)-level. Concerning joint coding of video sequences, sequence-level R-D control and optimization is performed to dynamically allocate the bandwidth among the video sequences to maximize the statistical multiplexing gain, that could be, for e.g., the use of the channel or the objective quality [24],[25].

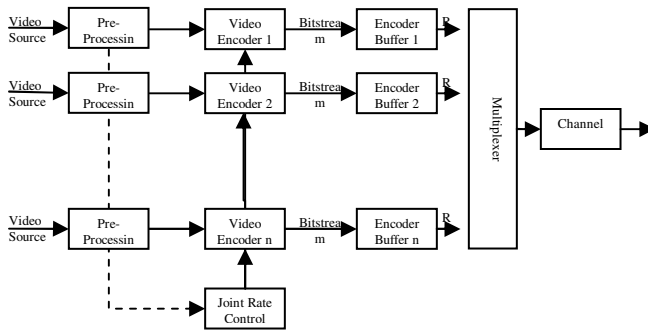


Figure 2. Block Diagram for Joint Coding.

In Figure 2, each video encoder generates encoded video and the resultant statistics. The joint rate module receives information regarding the relative complexities of each program and the channel buffer fullness. Each encoder changes its bit rate only when a new GOP begins.

A. Algorithm

Let $N_{gop,p}$ designate the total number of frames in a group of picture (GOP) for the p th video program, $n_{i,j,p}$ ($i = 1, 2, \dots, j = 1, 2, \dots, N_{gop}, p = 1, 2, \dots, M$) refer to the j th frame in the i th GOP of the p th video program, $B_c(n_{i,j,p})$ represent the occupancy of virtual buffer of the p th video program after encoding the j th frame in the i th GOP, $BitRate(n_{i,0,p})$ is the available bitrate at the i th GOP of the p th video program, and FrameRate is the predefined frame rate.

When the encoder starts to encode the i th GOP, the total bits allocated for the i th GOP of the p th video program can be determine by the following expression:

$$T_r(n_{i,0,p}) = \frac{BitRate(n_{i,0,p})}{FrameRate} N_{GOP} - B_c(n_{i-1,N_{GOP},p}) \Big|_{p=1,2,\dots,M} \quad (11)$$

If we consider the independent case this would be the available bandwidth. The aggregate bandwidth of all the video programs for the i th GOP can be determined as follows:

$$T_{aggregate_i} = \sum_{p=1}^M T_r(n_{i,0,p}) \quad (12)$$

The proposed joint rate control algorithm is based on the feedback model. Each encoder feeds the joint rate controller with coding statistics after finish encoding each picture. From section III, the results indicate that the rate fits well into a first order function of the SSIM metric. Thus, assuming a constant QP, the curve fitting results can be expressed as

$$R_{Q=fixed} = a + b \cdot SSIM \quad (13)$$

Where R denotes encoded bits, and a and b are zero-order and first-order constant coefficients extracted from curve fitting. Based on this linear relation, we proposed that by we can estimate the variation in quality for different bit rates in the neighborhood of a previous working point.

$$Quality = \frac{R_{new}}{R_{Q=fixed}} SSIM_{Q=fixed} \quad (14)$$

As our goal is to uniform the overall quality then we should make quality the same for each video sequence.

$$\alpha = \frac{SSIM_{Q=fixed}}{R_{Q=fixed}} \quad (15)$$

In our case we estimate α based on the previous encoded picture. For a 2 source and 3 sources case, the following equations would be use

$$\begin{cases} T_{i,1} = \frac{\alpha_2}{\alpha_1 + \alpha_2} \cdot T_{aggregate_i} \\ T_{i,2} = \frac{\alpha_1}{\alpha_1 + \alpha_2} \cdot T_{aggregate_i} \end{cases} \quad (16)$$

$$\begin{cases} T_{i,1} = \frac{\alpha_2 \cdot \alpha_3}{\alpha_1 \cdot \alpha_2 + \alpha_1 \cdot \alpha_3 + \alpha_2 \cdot \alpha_3} \cdot T_{aggregate_i} \\ T_{i,2} = \frac{\alpha_1 \cdot \alpha_3}{\alpha_1 \cdot \alpha_2 + \alpha_1 \cdot \alpha_3 + \alpha_2 \cdot \alpha_3} \cdot T_{aggregate_i} \\ T_{i,3} = \frac{\alpha_2 \cdot \alpha_3}{\alpha_1 \cdot \alpha_2 + \alpha_1 \cdot \alpha_3 + \alpha_2 \cdot \alpha_3} \cdot T_{aggregate_i} \end{cases} \quad (17)$$

V. EXPERIMENTAL RESULTS & DISCUSSION

We have implemented the proposed rate control scheme using the H.264 JM 10.2 encoder [26]. Simulations were performed using several video test sequences (Table 4), representing different level of complexity, each one exhibiting different combined levels of spatial detail and amount of movement.

Name	Res.	Duration	Characteristics
Akiyo	CIF	10 sec.	Still camera on human subject with synthetic background
Foreman	CIF	10 sec.	Fast camera and content motion with pan at the end
Football	CIF	10 sec.	Fast translational motion and camera panning; moderate spatial detail

Table 4 -Test sequences.

The test conditions under which our experiments were conducted are as follow: MV resolution = $\frac{1}{4}$ pel; RDO=ON; Search Range = 32; Frame Type = IPPP and Reference Frame = 1. The performance of our proposed scheme is evaluated in comparison with the original encoder JM 10.2. Two scenarios were studied. First each sequence encoded at fixed bit rate of 256kbps and then at fixed 512kbps. Table 5 presents results for independent coding (CBR). GOP1 and GOP2 correspond to Intra Period of 4 and 10 frames respectively.

Sequence	GOP	PSNRY (256kbps)	PSNRY (512kbps)
Akiyo	IPPP_GOP1	37,90	41,82
	IPPP_GOP2	41,21	44,06
Foreman	IPPP_GOP1	31,13	34,40
	IPPP_GOP2	33,05	36,18
Football	IPPP_GOP1	28,52	31,90
	IPPP_GOP2	29,18	31,91

Table 5 – PSNR for Independent Coding

With these three sequences 3 testing groups of three video

sources were created. Several combinations were simulated with jointly combine 3 video streams: Akiyo is represented with letter A, Foreman with letter B and Football with letter C.

BitRate	Metric	mux_ssim	mux_sad	mux_ssd
256	PSNR	2,35	-1,93	-1,63
256	SSIM	12,59	-5,97	-4,66
512	PSNR	1,56	-2,79	-2,56
512	SSIM	9,27	-8,92	-8,12

Table 6 – Average of Average Gain for different strategic Joint Coding strategies - IBBP GOP1 (3src).

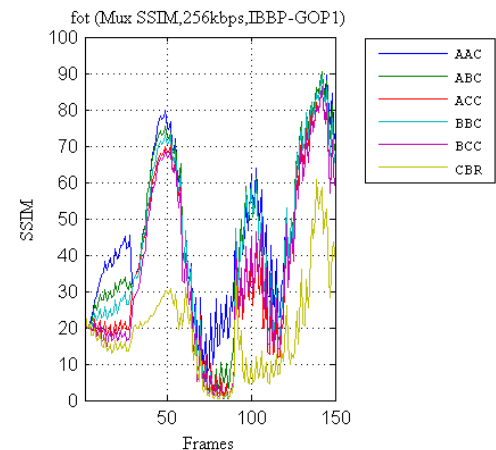


Figure 3. Joint coding Mux SSIM (IBBP GOP1; 256kbps; 3src) (Akiyo, Foreman, and Football)..

Figure 3 and Table 6 show preliminary results. As a reference simulation were also performed using SAD and SSD as metrics. Results show major improved in sequences with lower quality. These improvements are particularly positive in terms of SSIM gains rather than PSNR. Video sources with different combined levels of spatial detail and amount of movement benefit from this method. Nevertheless further simulations are being performed with longer sequences and with larger groups.

VI. CONCLUSION

We present a new approach based on a new R-D model, which combines SSIM metric and H.264 compression standard. We proposed a new complexity measure for estimation of the bit rate before encoding based on SSIM. As an illustration, we have applied this complexity metric to joint coding of video programs using H.264 codec. The experimental results confirm that our approach offer an true estimation for the rate and for the complexity. While we have analysed only a 2 sources scenario, this approach is flexible, in that it can be extended to additional video sources. Finally, we believe that our approach would be suitable also for other video compression standards.

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