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MPEG2 VIDEO PARAMETER AND NO REFERENCE PSNR ESTIMATION

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ABSTRACT

MPEG coded video may be processed for quality assessment or postprocessed to reduce coding artifacts or transcoded. Utilizing information about the MPEG stream may be useful for these tasks. This paper deals with estimating MPEG parameter information from the decoded video stream without access to the MPEG stream. This may be used in systems and applications where the coded stream is not accessible. Detection of MPEG I-frames and DCT (Discrete Cosine Transform) block size is presented. For the I-frames, the quantization parameters are estimated. Combining these with statistics of the reconstructed DCT coefficients, the PSNR is estimated from the decoded video without reference images. Tests on decoded fixed rate MPEG2 sequences demonstrate perfect detection rates and good performance of the PSNR estimation.

Index Terms— MPEG, No reference PSNR, quantization, parameter estimation, I-frame detection

1. INTRODUCTION

MPEG video coding is based on coding block based DCT (Discrete Cosine Transform) coefficients for I (Intra) frames. For the other frames, motion compensation is applied prior to the DCT. The distortion is determined by the quantization applied to the DCT coefficients. Decoded MPEG video may be transcoded for storage or further transmission or subjected to postprocessing to attenuate the coding artifacts and thereby increase quality. In some applications it may be desirable to assess the quality of the video or analyze it for forensic purposes. For all these tasks the parameters of the MPEG stream can provide useful information [1][2].

The parameters can be extracted from the coded stream, e.g. at the time of decoding. In many cases, the coded stream is not accessible, or from an architectural point of view, it is desirable not to access it. In some cases, a (non-encrypted) stream is not accessible out of the decoder or out of a third party (hardware) decoder. In other cases, it may be desirable just to use existing hardware/software decoder(s). Especially if we consider a set-up where the decoded video can come from a range of external decoders, it may be desirable to base the processing or analysis solely on the decoded signal. Improved performance may in this case be achieved by estimating some of the parameters used when coding the MPEG video, but based on the decoded video. As an extra challenge the output of the decoder may have been processed eg. by scaling before it is accessible.

As examples we consider estimating MPEG2 quality and extracting MPEG2 parameters. This may be used for aiding postprocessing. The MPEG video distortion and artifacts come from the DCT domain quantization. The distortion and strength of artifacts are correlated with the values of the quantization step sizes, which are given by the MPEG2 parameters quantization scale (Q_S) and

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quantization matrix (Q_M). The MPEG2 frame types (I frame or motion compensated) possess different artifacts and identifying I frames is also beneficial when transcoding. The DCT block size and DCT block boundary positions may be used to localize MPEG blocking artifacts in a deblocking filter. The MPEG2 block size is 8×8 , but the video data may have been rescaled after decoding.

In this paper we focus on some elements of MPEG analysis namely the important MPEG parameters: DCT block size and position detection (or validation), I-frame detection and for the I frames, estimation of the quantization step size. Furthermore we shall utilize this information to estimate the PSNR of the I frames. A likelihood based measure is introduced as part of the detection and estimation as well as validating that the stream has been MPEG2 coded.

Methods for (decoder side) no reference PSNR estimation, i.e. without access to the original video, have been presented based on MPEG parameters extracted from the streams [1]. In [3] the analysis is just based on the decoded stream. For the I frames, estimation of the quantization parameters and PSNR was presented by modelling the distribution of the DCT coefficients. Expressions and results were provided for fixed quantizer video. We extend this to fixed rate and thereby variable quantizer values and furthermore introduce a measure to validate the analysis.

The rest of the paper is organized as follows: MPEG2 decoding is briefly described in Sect. 2. Section 3 introduces the MPEG2 parameter estimation based on the decoded video: block size and position estimation, quantization step size estimation, and I frame detection. Section 4 describes the use of the recovered parameters for PSNR estimation on I frames. Experimental results are given in Sect. 5.

2. MPEG2 DECODING PROCESS

To provide the background and notation for the analysis, the decoding of MPEG2 I frames is briefly described. In MPEG2, the basic processing unit is the 16×16 pixel (luminance) Macro Block (MB), which is further divided into four 8×8 blocks, which are transformed using the DCT. The transformed coefficients are quantized, which is locally controlled by one quantizer scale value, Q_S , per MB.

The main processes of the MPEG2 decoder includes Variable Length Decoding (VLD), Inverse Quantization and Inverse DCT transformation as depicted on Fig.1. The output of the VLD, $I_Q(u, v)$, is an integer value, which represents the index of the quantization interval for the DCT coefficient at (u, v) . Based on this the DCT coefficients $F''(u, v)$ for the reconstruction are determined. The DCT AC coefficients, i.e. $(u, v) \neq (0, 0)$, are reconstructed in conformance with [4]. For the intra MB this gives

$$|F''(u, v)| = \left\lfloor \frac{|I_Q(u, v)| \times Q_M(u, v) \times Q_S}{16} \right\rfloor \quad (1)$$

where $\lfloor \cdot \rfloor$ denotes the floor function and $Q_M(u, v)$ denote the frequency dependent quantization matrix values. The four luma DCT

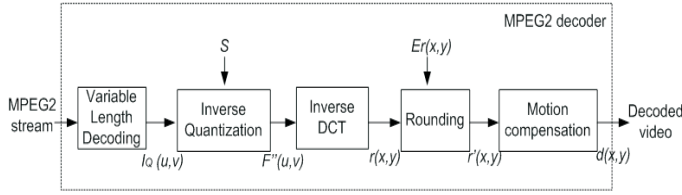


Fig. 1. The MPEG2 decoding process.

blocks in one macro-block are quantized using the same Q_S value, but Q_S may change from one MB to the next. It should be noted that F'' , I_Q , $Q_M(u, v)$ and Q_S all are integers.

After $F''(u, v)$ is reconstructed, the inverse DCT will convert $F''(u, v)$ to the inverse transformed value $r(x, y)$, which is rounded, and, if necessary clipped, to obtain integer values $r'(x, y)$ in the range $[0, 255]$. For intra blocks, $r'(x, y)$ will be directly output as the decoded video, $d(x, y)$. For non-intra blocks $r'(x, y)$ will further be combined with motion compensated data for the output $d(x, y)$.

3. MPEG2 PARAMETER ESTIMATION

MPEG2 parameters are estimated based on the decoded video $d(x, y)$. The focus is on estimating or detecting three main parameters: DCT blocksize and position, Quantization step size, and I frames. The overall process is shown in Fig. 2. The first DCT block boundary positions are estimated both horizontally and vertically. Based on that, the 8×8 block DCT is applied on each DCT block. (If the detected block size is not 8×8 , the DCT blocks should first be rescaled into 8×8 , then DCT transformed). Both frame and field DCT may be applied on MBs. The *MB_type* (frame & field MB) can be estimated by selecting the type minimum number of the zero DCT coefficients for an MB. Thereafter, Q_M and Q_S estimation are applied based on the reconstructed DCT coefficients $F'(u, v)$ (frame DCT if the MB is evaluated to be a frame MB, otherwise field DCT). The quantization step sizes (for each of the DCT coefficients) are recovered based on the estimated Q_M and Q_S . Furthermore the MB level mismatch (M_{MB}) is obtained. Frame level mismatch (M_F) is then calculated by the frame level average of M_{MB} . Finally I frames are detected by M_F .

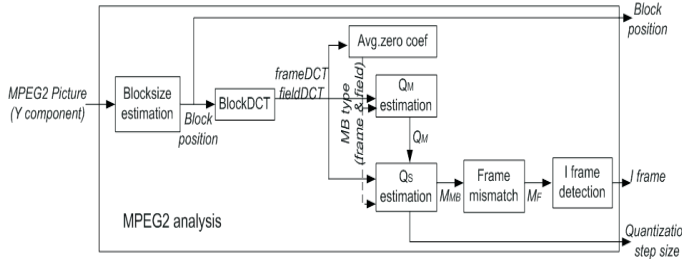


Fig. 2. MPEG2 frame level analysis.

3.1. Blocksize estimation

Absolute differences between adjoining pixels have been used to perform a blocking artifacts analysis [5]. Instead we calculate difference of differences and project the values on the horizontal and vertical axis (by summation). Applying a frequency analysis (using FFT) to these projected values gives clear peaks corresponding to the block structure.

3.2. Quantization step size estimation

For intra MBs, the quantized MPEG2 DCT coefficients can be recovered by applying an 8×8 DCT to the decoded video $d(x, y)$. Without the information of motion vectors and residues, it is intractable to recover non-intra DCT coefficients. We consider the general case where Intra/non-intra frame and MB type information is not known

(or uncertain). Initially, the proposed method treats all MBs as intra. After the processing, a decision about Intra/non-intra frames is made and validated. The Intra frame quantization step size, Δ , is a function of the DCT frequency (u, v) ,

$$\Delta(u, v) = \frac{Q_S \times Q_M(u, v)}{16} \quad (2)$$

It may be necessary to estimate both $Q_M(u, v)$ and Q_S . The basic idea of recovering Q_S (and $Q_M(u, v)$) on I frames is first to apply DCT on 8×8 blocks of the decoded video $r'(x, y)$ to recover the DCT coefficients, $F'(u, v)$, and based on these estimate $I_Q \times Q_S \times Q_M(1)$ for each DCT coefficient (u, v) , where Q_M is fixed at frame level and Q_S at MB level. In principle Q_S and $Q_M(u, v)$ are identical to the greatest common divisor (or a divisor of this) at MB and frame level, respectively [3].

This paper starts with Q_M estimation because Q_M is fixed for the whole frame, thus providing more statistics. If we restrict the analysis to a limited set of candidate Q_M , the problem is simplified to that of identifying (and validating) the selected candidate.

Having Q_M , $I_Q(u, v) \times Q_S$ may be recovered to estimate Q_S using a greatest common divisor approach. However, it is not certain that the values of $I_Q(u, v) \times Q_S$ obtained are the correct ones due to the non-linear processing of the rounding (and clipping) after the inverse DCT transformation and the integer division in the decoder. Empirically, we have noted that the distribution of the rounding error can be approximated by a Laplace distribution. Under this assumption, the estimation of Q_S can be expressed as a maximum likelihood problem. Taking the logarithm, this maybe expressed as finding the minimum of a sum of terms given by

$$\min_n (|F'(u, v) - n\Delta(u, v)|), n > 0 \quad (3)$$

where the argument is the distance between the reconstructed DCT value $F'(u, v)$ and the nearest possible reconstructed value of the MPEG2 decoder (2). Based on these ideas, practical and robust estimation schemes are presented below.

3.2.1. Q_M matrix estimation

The MPEG2 default intra Q_M is widely used in many applications. This was confirmed by analysis of some on-air MPEG2 sequences where also one more Q_M matrix was observed. These two matrices constitute our candidate set.

As noted Q_M is a sequence level parameter, and all AC coefficients of a given frequency, (u, v) is quantized using the same Q_M value. The four DCT blocks within the same MB have the same Q_S . The candidate Q_S values are tested on the MB and the Q_S having the smallest MB mismatch value, M_{MB} is selected:

$$\hat{Q}_M = Q_M(p) : \arg \min_{p \in \{Q_M\}} \sum_{MB} \min_{q \in \{Q_S\}} (M_{MB}(p, q))$$

where

$$M_{MB}(Q_M, Q_S) = \sum_{(u,v) \in MB} \left| \text{round} \left(\frac{F'(u, v) \times 16}{Q_M(u, v) \times Q_S} \right) - \frac{F'(u, v) \times 16}{Q_M(u, v) \times Q_S} \right|$$

The distance related to the log-likelihood formulation (3) is modified by normalizing by the quantization step size to make the mismatch independent of Q_S and Q_M , which will also favor the lower frequencies.

3.2.2. Q_S quantizer scale estimation

As MPEG2 has a unique Q_S for each MB, the decoded DCT coefficients $F''(u, v)$ within one MB will be distributed on integer multiples of the quantization step size [3] (with integer division truncation shift S) leading to the terms $(|I_Q| \times Q_S)$. For a single MB,

Q_S can then be estimated as the greatest common divisor (gcd) of the $(|I_Q| \times Q_S)$. The reconstructed values of $(|I_Q| \times Q_S)$ from the decoded video may be in error due to the decoder rounding error E_r , the integer division shift S and other possible processing steps (E_r and S are shown in Fig. 1). As the gcd operator is highly non-linear, where one wrong input value can lead to a completely wrong estimation, a more robust algorithm was developed. It is known that $0 \leq S < 1$, and we assume that the probability distribution of the rounding error in DCT domain $E_r(u, v)$ may be approximated by a Laplace distribution. Integer upper $(|I_Q| \times Q_S)_{up}$ and lower $(|I_Q| \times Q_S)_{down}$ bounds are defined as follows:

$$\left\lceil \frac{16(F^i - E_{max})}{QM} \right\rceil \leq |I_Q| \times Q_S \leq \left\lfloor \frac{16(F^i + E_{max})}{QM} \right\rfloor$$

where E_{max} was determined by experimentally fitting a Laplace distribution to the $E_r(u, v)$ for each DCT coefficient, and selecting E_{max} at the 99% level of the cumulative density function.

Several observations are used in the estimation algorithm below:

- 1) The set $\{Q_S\}$ of all potential values of Q_S are given by the MPEG2 Q_S table, which is defined by MPEG2 [4].
- 2) For a single MB, the Q_S upper bound, Q_S^{up} , can be obtained by $\min(|I_Q \times Q_S|_{up})$ (min is over the frequencies (u, v) for all the non-zero DCT coefficients).
- 3) MPEG2 has a bias towards maintaining the same Q_S value as the previous MB. Therefore the previous Q_S can be used for estimation.

The Q_S estimation algorithm For each MB do

1. For all the AC DCT values, $F^i(u, v)$ ($u, v \neq (0, 0)$), within the current MB, calculate $F_{Q_S}(u, v) = F^i(u, v) \times 16/Q_M$, $(|I_Q(u, v)| \times Q_S)_{up}$ and $(|I_Q(u, v)| \times Q_S)_{down}$.
2. Round $F_{Q_S}(u, v)$ to the nearest even integer value $K(u, v)$.
3. Set all $K(u, v)$ less than 4 to zero (All DC values are set to 0).
4. Calculate the Q_S upper bound Q_S^{up} by $\min(|I_Q \times Q_S|_{up})$ (min is over the non-zero DCT coefficients).
5. For $j \in \{Q_S\}$ and $4 \leq j \leq Q_S^{up}$,

$$\hat{Q}_S = \arg \max_j [N_1(j) + N_2(j)]$$

where $N_1(Q_S)$ is the number of DCT coefficients for which $K(u, v) = Q_S$, and $N_2(Q_S)$ is the number of $K(u, v)$, which are divisible by Q_S .

6. For MBs, which do not contain any non-zero AC coefficients, the steps above do not provide a result. Instead, the estimated \hat{Q}_S value from the previous MB is used for the current MB.

3.3. Validation and I frame detection

MPEG2 I frame detection based on the number of zero coefficients in each frame has been proposed [6]. Based on this number, an adaptive threshold filter was defined to determine an I frame threshold. Two limitations for this method are that it uses a preset value for the (approximate) GOP length and an initial value of the decision threshold.

Here a novel I frame detection method is proposed which makes decisions at frame level and therefore may be applied to adaptive GOP structures. A frame level mismatch measure M_F , is introduced to measure how accurate the step size is estimated,

$$M_F = \sum_{MB} M_{MB}(\hat{Q}_M, \hat{Q}_S)$$

Small values of M_F (related to the distance between $F^i(u, v)$ and the closest multiple of the quantization step size) are obtained

when the Q_S values of the frame are correctly estimated. For I frames, where a very high percentage of the Q_S values are correctly estimated, the mismatch, M_F , is mainly due to the rounding error E_r and integer division shift S . For the other frame types, the motion compensated contributions will lead to many misleading contributions to the DCT coefficients which in turn leads to wrong quantization step size estimates. A threshold is applied to M_F .

4. PSNR ESTIMATION

The I frame peak signal to noise ratio (PSNR) can be estimated based on the predicted quantization step size values. In [3], no reference PSNR estimation was presented for I frames which are MPEG2 coded using a fixed Q_S . The value of Q_S was estimated based on a frequency analysis of the DCT coefficients for each frequency, (u, v) . The distribution of the DCT coefficients was assumed to follow a Laplacian distribution prior to coding, but the parameter of the distribution (λ) was estimated based on the DCT transform on the decoded video.

A method was given in [3] for calculating the overall mean square error DC distortion ε_{DC}^2 and AC distortion ε_{AC}^2 . ε_{AC}^2 was derived as:

$$\varepsilon_{AC}^2 = 2\lambda^2 - \frac{2\lambda\Delta e^{-\alpha/\lambda} e^{-\Delta/2\lambda}}{1 - e^{-\Delta/\lambda}} \left[\frac{\alpha}{\lambda} + 1 \right] \quad (4)$$

where Δ is the quantization step size as (2), and α is the shift factor in the MPEG-2 quantization scheme. λ is the Laplacian parameter for each DCT coefficient. The value of Δ , α and λ can vary for different AC frequencies (u, v) , leading to a dependency on Q_M and Q_S .

The average distortion D at frame level was calculated by combining the estimated Q_S and the coefficient distribution estimation.

$$D = \frac{1}{64} [\varepsilon_{DC}^2 + \sum_{i=1}^{63} \varepsilon_{AC}^2(i)] \quad (5)$$

Usually sequences are coded using rate control, in which case Q_S will vary from MB to MB within one frame. The distortion expression, (6) is here generalized to allow Q_S to vary over MBs,

$$\hat{D} = \frac{\varepsilon_{DC}^2 \times B_v \times B_h + \sum_{Q_S} \sum_{Q_M} \varepsilon_{AC}^2(Q_S, Q_M) \times N_{AC}(Q_S, Q_M)}{B_v \times B_h + \sum_{Q_S} \sum_{Q_M} N_{AC}(Q_S, Q_M)} \quad (6)$$

where B_v and B_h are the number of DCT blocks vertically and horizontally and $N_{AC}(Q_S, Q_M)$ is the number of AC coefficients for the (Q_S, Q_M) combination.

In [3] λ was estimated for each DCT coefficient based on analysis of the second moment for each of the first 24 AC coefficients (in zigzag scan order). Using the second moment will lead to over-estimation of the parameter in case of outliers (or a heavy tail distribution.) Our guess is that this may have lead the authors to apply a different estimator (assuming $2\lambda^2$ as the variance) for the high frequencies to counteract this effect.

Estimating λ based on the number of zero coefficients provides a faster and simpler estimation, which readily matches the use of decoder side statistics. The idea was introduced in [7], and we derive the λ estimate:

$$\lambda(Q_S, Q_M) = -\frac{\Delta/2 + \alpha}{\ln(1 - p_0(Q_S, Q_M))} \quad (7)$$

where $p_0(Q_S, Q_M)$ is the ratio of number of zero coefficients for all the coefficients quantized by Q_S and Q_M , $p_0 = N_0/N$, where N_0 is the estimated number of zero coefficients estimated by the number of reconstructed values in the interval $[-\Delta/2 - \alpha, \Delta/2 + \alpha]$, and N is the total number of coefficients.

5. RESULTS

We used four SD progressive test sequences CITY, SOCCER (SOC), ICE and CREW having a resolution of 704×576 . The sequences were coded at constant bitrates of 2M, 3M and 4Mbits/s using MPEG2 default intra Q_M and frame MB processing. The MPEG GOP length was $N=12$ and 2 B-frames ($M=3$) between P-frames were used in this test.

The MPEG2 parameters were extracted only using the decoded Y component. Two candidate intra Q_M were used as mentioned previously. The correct Q_M was identified for all frames. Since Q_S can vary from MB to MB, MB based Q_S estimation was performed. For the 12 MPEG2 coded sequences (100 frames for each), very accurate estimates was achieved by the Q_S algorithm (Table 1). The overall average true Q_S value is 15.33 and the average estimated Q_S value is 15.41.

As a test, the decoded test sequences were also up-scaled to 1080p, the block size was identified and thereafter down-scaled using cubic interpolation. The same MPEG2 analysis scheme was applied to these re-scaled sequences with different parameters. The rounding error E_r range was adjusted to $[-2E_{max}, 2E_{max}]$. In Q_S estimation algorithm Step 5), $j \geq 6$ instead of 4. An accurate Q_S estimation is also achieved in this case with an overall average Q_S of 15.45, demonstrating the robustness of the algorithm.

Table 1 shows the I frame PSNR estimation results using λ values dependent on both Q_M and Q_S . (CITY2 refers to CITY at 2M.) Based on the Q_S estimation of Sect.3.2, method M1 adjusts ε_{AC}^2 (4) by the MB based Q_S (instead of the average Q_S) and uses the new average distortion function in (6). For each (Q_S, Q_M) , λ is estimated as in [3]. Based on M1, M2 instead applies $\lambda(Q_S, Q_M)$ estimation based on the number of zero coefficients, by (7).

In Table 2, a weighted average over $\lambda(Q_S, Q_M)$ is used. The λ_{avg} is independent of Q_S and only depends on $Q_M(u, v)$, i.e. AC positions (u, v) . Methods M3 and M4 are based on M1 and M2 respectively, but replacing $\lambda(Q_S, Q_M)$ by λ_{avg} . In Tables 1 and 2, PSNR estimation results based on the actual quantization step size values are also given in parentheses for comparison. The average is calculated over all the I frames among the 100 frames of each sequence. It may be noted that the PSNR estimates using estimated and actual Q_S values are virtually identical.

Figure 3 shows the I frame estimation results for the 12 coded sequences (100 frames for each sequence at 2M, 3M and 4Mbits/s) concatenated to one video stream. I frames are marked in (red) bars and the other frames are in green. The frames, which are assigned a wrong frame type are marked in (blue) squares. It is shown that M_F gives a very clear and better separation of I frames than for the number of zero coefficients, thus also validating the analysis. The method proposed uses a mismatch threshold at 0.03. Compared with our implementation of [6] based on zero coefficients, it improves the accuracy from 99.17% to 100%.

Table 1. I frame , Q_S and PSNR estimation results, ($\lambda(Q_S, Q_M)$)

	CITY2	SOC 2	ICE 2	CREW2	CITY3	SOC 3	ICE 3	CREW3	CITY4	SOC 4	ICE 4	CREW4
avg Q_S	24.70 (24.70)	29.29 (29.19)	11.11 (11.21)	21.53 (21.35)	16.67 (16.67)	18.02 (18.04)	7.50 (7.34)	12.79 (12.77)	13.12 (13.12)	13.90 (13.92)	6.24 (5.69)	10.00 (10.00)
PSNR	31.76	31.52	39.82	35.91	33.96	33.96	41.56	38.01	35.38	35.47	42.75	39.08
M1	31.35 (31.36)	30.52 (30.55)	38.25 (38.26)	33.26 (33.39)	34.59 (34.59)	34.19 (41.63)	41.48 (41.63)	37.12 (37.17)	36.62 (36.62)	36.31 (36.31)	43.12 (43.78)	39.11 (39.13)
M2	31.88 (31.88)	32.09 (32.10)	37.95 (37.95)	35.32 (35.36)	33.95 (33.95)	34.28 (34.27)	40.07 (40.17)	37.57 (37.57)	35.24 (35.34)	35.68 (35.67)	41.19 (41.66)	38.81 (38.80)

6. CONCLUSIONS

Based on decoded MPEG2 video (without access to the MPEG stream), methods for estimating some coding parameters were pre-

Table 2. I frame , Q_S and PSNR estimation results, (λ_{avg})

	CITY2	SOC 2	ICE 2	CREW2	CITY3	SOC 3	ICE 3	CREW3	CITY4	SOC 4	ICE 4	CREW4
PSNR	31.76	31.52	39.82	35.91	33.96	33.96	41.56	38.01	35.38	35.47	42.75	39.08
M3	31.50 (31.50)	30.72 (30.72)	38.54 (38.53)	33.63 (33.63)	34.71 (34.71)	34.34 (34.34)	41.89 (41.90)	37.40 (37.40)	36.72 (36.72)	36.43 (36.43)	43.96 (43.99)	39.34 (39.34)
M4	31.87 (31.88)	32.07 (32.09)	38.38 (38.33)	35.07 (35.11)	34.08 (34.08)	34.42 (34.42)	40.88 (40.91)	37.79 (37.80)	35.54 (35.54)	35.83 (35.83)	42.20 (42.40)	39.21 (39.20)

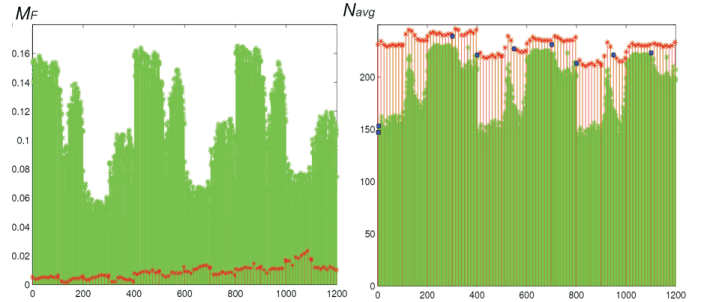


Fig. 3. I frame detection results for frames of the concatenated sequence. Left) By M_F and Right) By the average number of zero coefficients per MB, N_{avg} .

sented. For I-frames, an algorithm to estimate the MB quantizer scale parameter was given. Tested on MPEG2 video with fixed bitrate and thereby varying Q_S , very good estimates were obtained. Combined with modeling and estimating the DCT coefficients distribution, good no reference estimates of the I frame PSNR was obtained. The difference of using the estimated and the actual Q_S values was negligible. A novel I frame detector operating on individual frames based on evaluating the validity of the I frame Q_S estimation was also presented, showing a clear separation of the I frames from the motion compensated frames.

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