

Quality Estimation of Video Transmitted over an Additive WGN Channel based on Digital Watermarking and Wavelet Transform

Mohamed S. El-Mahallawy, Attalah Hashad, Hazem Hassan Ali, and Heba Sami Zaky

Abstract—This paper presents an evaluation for a wavelet-based digital watermarking technique used in estimating the quality of video sequences transmitted over Additive White Gaussian Noise (AWGN) channel in terms of a classical objective metric, such as Peak Signal-to-Noise Ratio (PSNR) without the need of the original video. In this method, a watermark is embedded into the Discrete Wavelet Transform (DWT) domain of the original video frames using a quantization method. The degradation of the extracted watermark can be used to estimate the video quality in terms of PSNR with good accuracy. We calculated PSNR for video frames contaminated with AWGN and compared the values with those estimated using the Watermarking-DWT based approach. It is found that the calculated and estimated quality measures of the video frames are highly correlated, suggesting that this method can provide a good quality measure for video frames transmitted over AWGN channel without the need of the original video.

Keywords—AWGN, DWT, PSNR, Watermarking, Video Quality.

I. INTRODUCTION

IN every part of the video chain, from the source to the display, the video may be impaired by noise. Additive White Gaussian Noise (AWGN) is the most important noise type and it primarily enters the system during the analogue transmission phase from the broadcasting of the composite video signal to the reception of the signal at the user's premises [x,y]. In many video processing applications, such as video quality enhancement, compression, format conversion, de-interlacing, motion segmentation, video broadcasting, transmission control etc., accurate knowledge of the quality of

the video sequence is of crucial importance for tuning the parameters of the corresponding video processing algorithm [1], [2].

Based on the dependence of a reference image for evaluation, the image quality measurement metrics can be divided into three categories: the full-reference metrics, reduced-reference metrics, and no-reference metrics [3]. To evaluate video quality, PSNR, weighted PSNR (wPSNR), and Watson model are commonly used. These classical metrics require knowledge of the original video because they are based on point-to-point calculation between the original video and the degraded video in the spatial domain or in the frequency domain. This requirement makes these metrics less than optimal for those applications that require video information to be delivered through a network (e.g., mobile video). For these applications, it might be impossible or too expensive to allocate the extra bandwidth required to send information about the original video [4].

On the other hand, reduced-reference quality metrics are based on methods that require partial information of the reference and no-reference quality metrics are based on methods that can evaluate image quality without any information of the original image. These two categories of metrics are desirable because they provide convenience for the video quality evaluation and real-time signal quality evaluation by avoiding the transmission of a large amount of information that is typically required for sending the original video signal. However, these two categories of objective video quality metrics do not have the accuracy that can be obtained with full-reference quality metrics [4].

Recently, a number of watermarking-based quality measurement metrics have been proposed [4]–[8]. These watermarking-based metrics all estimate the image quality by examining the degradation of the watermark extracted at the receiver side. In [6], a novel image quality measurement method using digital watermarking embedded in the DWT domain is introduced. The watermark is embedded in an original image so that any loss of quality of that image is reflected in the quality of the watermark. Upon retrieval, the degradation of the watermark can be used to measure objectively the loss of quality of the original image. The proposed method was very effective for predicting the effect on image quality of JPEG compression.

Mohamed S. El-Mahallawy, Assistant Professor of Electronics & Electrical Communications, is with Faculty of Engineering, Arab Academy for Science & Technology and Maritime Transport, Cairo, Egypt (e-mail: mahallawy@aast.edu).

Attalah Hashad, Assistant Dean of the faculty of Engineering, is with Arab Academy for Science & Technology and Maritime Transport, Cairo, Egypt (e-mail: hashad@cairo.aast.edu).

Hazem Hassan Ali, Head of Department of Electronics & Electrical Communications, is with Faculty of Engineering, Arab Academy for Science & Technology and Maritime Transport, Cairo, Egypt (e-mail: hazem@aast.edu).

Heba Sami Zaky, Teaching assistant of Electronics & Electrical Communications, is with Faculty of Engineering, Arab Academy for Science & Technology and Maritime Transport, Cairo, Egypt (e-mail: heba_sami@hotmail.com).

A more Accurate Algorithm is proposed by Wang *et al.* [4], [9], the proposed algorithm improved the estimated PSNR of the image by adjusting the watermarking embedding parameters to reduce the error between the estimated and calculated PSNR and this takes place at the encoder side, these parameters had to be sent to the decoder to retrieve the watermark. For some applications, it might be impossible or expensive to allocate an extra bandwidth required to send information about the embedding parameters.

In our paper, DWT-based watermarking algorithm proposed by [6], without adjusting the watermarking embedding parameters, is deployed to be used for estimating the objective quality of the video sequences contaminated by an AWGN which is of interest in many video applications [2].

II. WAVELET-BASED DIGITAL WATERMARKING TECHNIQUE

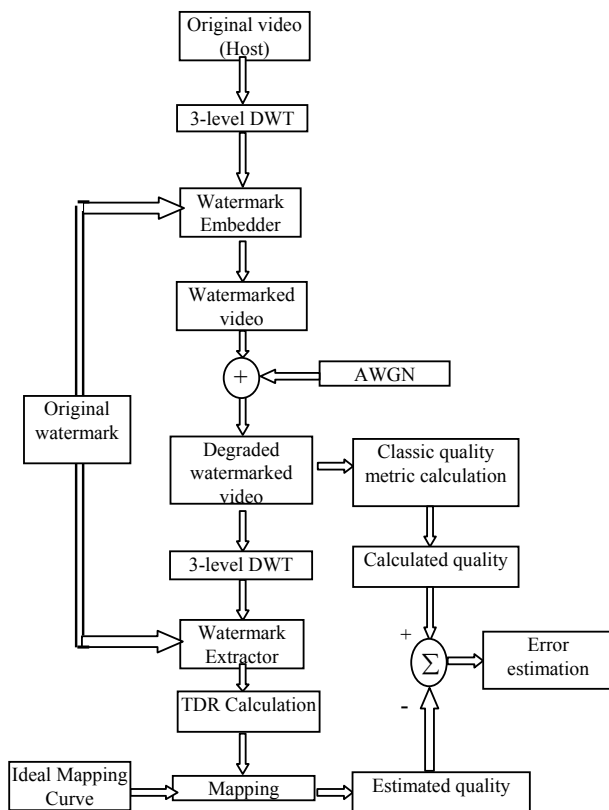


Fig. 1 Watermarking based video quality evaluation method

Fig. 1 illustrates the used fragile watermark embedding scheme for video quality evaluation which is designed to estimate the quality of the received video in terms of PSNR without the need of the original video [6]. The watermark embedding process is implemented in the DWT domain, because the DWT can decompose video frames into different frequency components (subbands) [10], [11]. Different frequency components have different sensitivities to noise, according to noise type, which makes it much easier to control the watermark vulnerability. The vulnerability of a watermark

is mainly affected by two factors: the amount of watermark bits embedded into each frequency component of the video frame and the corresponding watermark embedding strength which is controlled by the quantization parameter. At the receiver side, the frame quality is estimated based on the degradation of the extracted watermark [9].

A. Watermark Embedding and Extraction

As shown in Fig. 1, the watermark embedding and extraction are implemented in the 3-level DWT domain of the original video frame using the quantization method [6], [12]. Equation (1) shows how the quantization method works and how the quantization parameter (Δ) controls the watermark vulnerability.

$$Q(e) = \begin{cases} 1, & \text{floor}\left(\frac{\text{DWT coefficient}}{\Delta}\right) \text{ is even} \\ 0, & \text{floor}\left(\frac{\text{DWT coefficient}}{\Delta}\right) \text{ is odd.} \end{cases} \quad (1)$$

Using (1), each DWT coefficient is assigned a binary 0 or 1. The binary bits associated with the DWT coefficients are denoted as $Q(e)$. A watermark bit is embedded into a DWT coefficient by checking the watermark bit, $W(e)$, and the $Q(e)$ associated with the target DWT coefficient. If $W(e) \neq Q(e)$, the DWT coefficient is changed by adding the quantization parameter (Δ) to make the $Q(e)$ of the modified DWT coefficient equal to $W(e)$. If $W(e) = Q(e)$, we do not change the DWT coefficient. Each watermark bit is embedded into M selected DWT coefficients to add some redundancy [4].

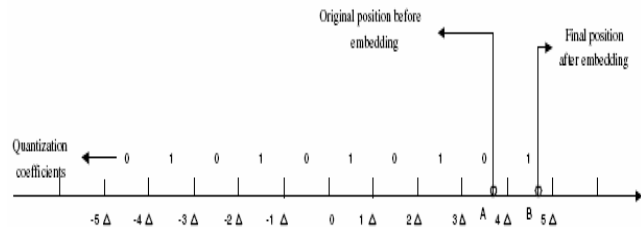


Fig. 2 Watermark embedding scheme [4]

Fig. 2 shows the quantization details. For example, we want to embed a watermark bit 1 into the current point, A, which corresponds to a quantization value 0. Because $Q(A)$ is not equal to the watermark bit, we need to force the point to reach B which corresponds to 1 by adding Δ to A. Δ is defined by:

$$\Delta = \frac{\max(\text{coefficient}) - \min(\text{coefficient})}{k} \quad (2)$$

where, "coefficient" is the n^{th} subband DWT coefficients of a video frame, while parameter k is set up by the experimenter to adjust Δ . A smaller Δ will maintain better fidelity after embedding, while it also will make the watermark more sensitive to attacks. Δ will directly affect our quality

monitoring effect. So another important issue is to try to find a balance between robustness and invisibility [6].

After 3-level DWT decomposition, the video frame is decomposed into 10 blocks or subbands. Each of the 10 blocks will be assigned one quantization parameter which determines the watermark embedding strength for the block. Each block contains different frequency components of the video frame.

During extraction, the 3-level DWT is first applied to the received watermarked video frame. By checking the DWT coefficients using (1), the watermark information bits can be retrieved. Then the video frame quality evaluation can be carried out based on the extracted watermark information bits.

B. Quality Evaluation

Adding WGN to the watermarked video degrades the video quality. To evaluate the quality of the degraded video, we first calculate the True Detection Rate (TDR) of the extracted watermark using (3).

$$\text{TDR} = \frac{\text{number of correctly detected watermark bits}}{\text{Total number of watermark bits}} \quad (3)$$

The TDR indicates the degradation of the watermark. The smaller the TDR value, the more severe the degradation of the watermark. With the decrease of the PSNR, the TDR values decrease monotonically. Therefore, the quality of the degraded video can be estimated by mapping the calculated TDR to PSNR using a respective empirical ideal mapping curve estimated offline at the transmitter. The ideal mapping curve is the basis for quality evaluation and it is a pre-defined relationship between the calculated TDR values after the watermark extraction and the quality values calculated with the standard quality metric such as PSNR calculated by:

$$\text{PSNR} = 10 \log_{10} \frac{L^2}{\text{MSE}} \quad (4)$$

$$\text{MSE} = \frac{1}{N} \sum_{i=1}^N (x_i - y_i)^2 \quad (5)$$

where N is the number of pixels in the video frame, x_i and y_i are the i^{th} pixels in the original and the distorted video frames, respectively. L is the dynamic range of the pixel values. For an 8bits/pixel monotonic signal, L is equal to 255

At the receiver, after watermark extraction, the calculated TDR value could possibly lie between two neighboring values on the ideal mapping curve and in this case linear interpolation is used to estimate the PSNR based on the calculated TDR value.

III. SYSTEM IMPLEMENTATION AND PARAMETER ESTIMATION

A binary equivalent of a meaningful text watermark with a size of 1428 bit is embedded in the transformed video frames.

As the WGN has an effect on all the frequency components of the video frames, we need to embed the watermark with equal vulnerabilities in all the frequency bands of video frames to reflect the equal drop in PSNR. Since the DWT can

transform the video frame into different frequency distributions, we can apply vulnerability adjustment according to the type of the noise. Different portions of the watermark will be embedded into the 10 wavelet decomposed blocks. A watermark bit portion is the percentage of a selected part of the watermark bits over the total watermark bits. For WGN we adjust the watermark bit portions that will be embedded into the decomposed blocks as shown in Fig. 3 in order to make the TDR goes linearly with the PSNR.

LL3 6.125%	LH3 6.125%	LH2 8.33%	LH1 16.66%
HL3 6.125%	HH3 6.125%		
HL2 8.33%		HH2 8.33%	
HL1 16.66%			HH1 16.66%

Fig. 3 Watermark bit portions in different DWT subbands

During Quantization in each DWT band, M coefficients (M is adjusted empirically to be equal 10) are chosen to embed the current watermark bit and are clustered as a block. Another M coefficients block of the rest coefficients are used to embed the next watermark bit. Keep embedding until no watermark bit or less than M coefficients left.

The extracted watermark bit is detected to be 1 if the total number of detected 1 in each block is greater than the number of detected 0, and to be 0 if the total number of detected 0 is greater than the number of detected 1.

During quantization, the quantization parameter k is chosen empirically to be 80 to achieve an acceptable distortion for the video frames due to watermark embedding (acceptable PSNR_w) and to achieve a least average errors between the estimated and calculated PSNR of video frames contaminated with AWGN.

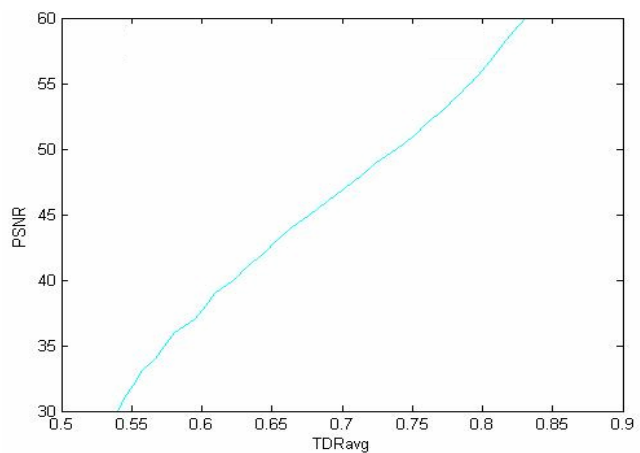


Fig. 4 Ideal Mapping Curve

Fig. 4 shows the ideal mapping curve used in estimating video quality using the PSNR objective quality measure. The ideal mapping curve is generated using 120 frames from six different movies [http://trace.eas.asu.edu], with the quantization parameter k used equal 80 and the number of redundant coefficients M used in the quantization process equal 10. The PSNR's of the watermarked frames ($PSNR_w$) before adding WGN used are all above 40 dB. In Fig. 4, the horizontal axis is the mean of the TDR values calculated at a certain PSNR, for all the 120 frames used in the ideal mapping curve estimation process. The vertical axis is the calculated PSNR of the video frame after the addition of the WGN.

IV. EXPERIMENTAL RESULTS

In our evaluation experiments, 10 different-movies, each with 90 frames other than that used in the ideal mapping curve estimation are used [http://trace.eas.asu.edu].

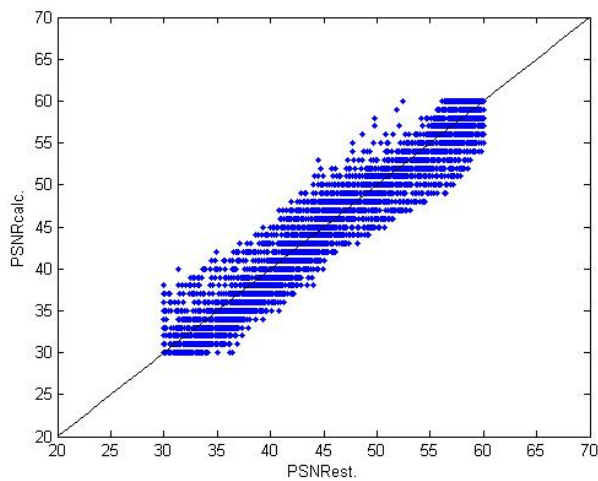


Fig. 5 PSNR estimated versus calculated PSNR

Fig. 5 shows the correlation between the estimated quality values and the calculated quality values for all the frames used in our experiments. In this figure, the horizontal axis is the estimated quality in terms of PSNR. The vertical axis is the calculated quality in terms of PSNR. The solid line with a 45-degree angle is the match line indicating that the estimated quality equals to the calculated quality. The distribution of the scattered points in the figure indicates the accuracy of the estimated quality compared with the calculated quality. The closer the scattered points to the solid line, the more accurate the estimated quality compared with the calculated quality. If the frame quality can be estimated with no errors, all the points should be exactly on the match line.

To measure how close the scattered points to the solid line, we used the Mean Absolute Error (MAE) calculated by:

$$MAE = \frac{1}{V * F} \sum_{i=1}^V \sum_{j=1}^F |PSNR_{est} - PSNR_{calc}| \quad (6)$$

where V is the number of movies used in the evaluation, F is the number of frames/video. $PSNR_{est}$ is the estimated peak signal to noise ratio and $PSNR_{calc}$ is the calculated peak signal to noise ratio.

Table I shows the accuracy of quality evaluation in terms of MAE at different values of redundant wavelet coefficients M used during the quantization parameters. The smaller the MAE, the more accurate the quality estimation is achieved. It also shows the average $PSNR_w$ calculated for the video frames after watermark embedding for different values of M . The higher the $PSNR_w$ the less distortion is applied to the video frame due to watermarking embedding process.

TABLE I
ACCURACY OF QUALITY EVALUATION

M	Average $PSNR_w$	MAE
50	39.95	2.07
40	41	2.05
30	42.39	1.99
20	44.40	1.90
10	48.42	1.86
5	54.63	2.27
1	78.04	10.16

V. CONCLUSION

In this paper, we presented an evaluation for a video quality estimation method based on digital watermarking for video frames transmitted over a WGN channel. The watermark is embedded by quantizing the DWT coefficients of the video frame and the degradation of the watermark due to the effect of the additive WGN reflects the degradation of video frame quality. The most important aspect of the used method is that the video quality estimation of noisy frames can be achieved in a good accuracy (within 2dB error) without the need for accessing information pertaining to the original video. The TDR computed at the receiver/user side can be used to estimate the video frame quality in terms of PSNR. The evaluation demonstrated the effectiveness of the used scheme in the video quality estimation in case of WGN effect. Thus the used method for automatic video quality estimation is ideal for the monitoring of frame quality for broadcasting and multimedia applications.

The used technique can be also implemented to track Watson model by using TDR. Watson model estimates the perceptual distance of the degraded video using the Watson Just Noticeable difference (JND) metric [13]. Also this algorithm can be tested and evaluated in estimating the quality of videos contaminated by another types of noise other than WGN.

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