A high capacity data hiding algorithm for H.264/AVC video

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A High Capacity Data Hiding Algorithm for H.264/AVC Video

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Abstract – This article presents an information hiding algorithm for H.264/AVC video stream. It utilizes position of the last non zero (LNZ) level of quantized discrete cosine transform (QDCT) block to embed information bits. Since only the high frequency levels are changed, it can guarantee a high Peak signal-to-noise ratio (PSNR) and slight increase in bitrate after the watermark embedding. The extraction process is not complex thus the proposed technique is an excellent solution for real-time applications such as broadcasting. Experimental results on several test sequences demonstrate that the proposed approach can realize blind extraction with real-time performance, it also provides very high capacity, low distortion and increase in bit-rate by about 0.5 percent.

Index Terms – Video data hiding, H.264/AVC, DCT, Watermarking, Multimedia security

1. Introduction

With the progress of computer and broadband internet technologies, nowadays it is possible to stream high quality video and to watch video online. Websites such as YouTube, DailyMotion, and iFilm provide free watching and download services, while portable devices such as iPod, smartphone, and tablet make it possible to playback a video anywhere anytime. Thus, digital video has become a popular multimedia content for both online and offline environments. Therefore it is important to discover ways to protect the contents from malicious use, and to design efficient methods to search the desired contents in the database, secure ways to provide extra features for upgraded viewers, and reliable techniques to recover from transmission error for uninterrupted viewing for the future of digital video.

Data hiding methods embed a secret signal directly into the original media in an imperceptible manner. In video data hiding, the watermark can be embedded either into an uncompressed video sequence (raw data) or compressed video stream, although the great majority of streamed video through the Internet are compressed, so data hiding in compressed video has a wider impact than data hiding in uncompressed video.

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Transparency, capacity, and security are three major challenging issues of a video data hiding system. Robustness is a property of a watermarking system which is considered in some applications such as copyright protection. In data hiding applications, robustness is not a priority since such applications are more aimed to achieve high transparency along with embedding a great deal of secret bits [1]. The application of our proposed algorithm is mainly in covert communication and error concealment, but it can also be used in scenarios such as [2] where data hiding techniques are used to measure the quality of the compressed video in the absence of the original reference (such as reduced reference model), by predicting the quality from the degradations of the extracted hidden message. Another application of data hiding can be seen in [3], which uses data hiding to enable real time scene change detection in compressed video. Finally, data hiding is a suitable solution for error detection and concealment in video transmission, where edge orientation information and number of bits of a block are embedded in the bit stream for that purpose [4].

In general, the existing data hiding systems rely on embedding information bits in discrete cosine transform (DCT) coefficients, motion vectors (MVs), quantization scale or prediction modes. Ref [5] uses DCT coefficients and the parity of the quantized coefficients to hide a message. The work in [6] presents a solution for using the magnitude of MVs for data hiding. The least significant bit of both components of candidate motion vectors are used to embed a secret message. The candidate motion vectors are chosen based on the prediction error of the underlying macroblock. MVs related to high prediction errors are selected. A prediction error threshold per frame is calculated and transmitted in the video bit stream to guide the decoder in recognizing the MVs that carry the secret information bits. Ref [7] proposes the use of intraprediction modes to embed secret message bits. Furthermore, the work in [8] utilizes the block types and modes of intracoded blocks of H.264/AVC to hide message bits. Data hiding technique can also be applied before compression, such as embedding hidden messages into the pixels and then compressing them as I-frames [9].

Recently, several researchers have focused on developing data hiding systems in the compressed domain [10] [11] [12] [13] [14] [15] [16]. However, the complex encoding nature of modern encoders such as H.264/AVC [17] creates several constraints for hiding data in the coded video sequences. The restrictions include:

a. Embedding even a little data into the coded video sequence would result in a great deal of changes on both the bit-rate and the reproduced video quality.

b. It is difficult to make a cost effective trade-off between the bit-rate increase and video quality degradation when embedding secret data into the coded bit-stream.

c. To increase hiding capacity, increase in bit-rate or video quality degradation is sacrificed [18].

Due to these constraints, designing a video data hiding system in the compressed domain is more difficult than other domains. Two methods [19]-[20] have applied the traditional reversible methods to H.264/AVC directly. Lie et al [19], utilize difference expansion (DE) [21] to embed secret bits into the quantized discrete cosine transform (QDCT) coefficients for error concealment, while Chung et al [20] suggest an efficient algorithm which utilizes histogram shifting [22] through QDCT coefficients to embed motion vectors (MV) for error concealment, but considering the histogram shifting rules, the system should find the peak and zero points to shift and embed data from the embedding target. According to the Context-adaptive variable-length coding (CAVLC) rule [23], changing the number of QDCT coefficients or the length of the Variable-length codes (VLC) words can significantly increase the bit-rate or reduce the PSNR.

In our proposed method after performing DCT and quantization phases in H.264/AVC, some 4×4 blocks are selected for embedding. The method takes advantage of high frequency levels to gain from lower sensitivity of Human visual system (HSV) to higher frequency distortions. Embedding in the low frequency levels of 4×4 blocks, which carry perceptually important information, results in obvious quality distortion in the watermarked video. Therefore, in the proposed scheme, the last non zero QDCT coefficients of 4×4 blocks are used, which are in the high frequency band to embed the watermark. The scheme utilizes the positions of the last non zero (PLNZ) levels to embed information bits. Experimental results and analysis presented in Section 3 will demonstrate that the suggested system provides very high capacity and low quality degradation while limiting the bit-rate increase to about 0.5%.

It should be noted that, although in this paper H.264/AVC is chosen to demonstrate the proposed method, there is no loss of generality and the method can be applied to any modern video codec, such as the HEVC, which transforms macroblocks using DCT or operations similar to DTC, leading to frequency coefficients. The rest of the paper is organized as follows: in section 2 the proposed data hiding scheme is presented. Section 3 introduces the experimental results. Finally, section 4 gives some concluding remarks.

2. THE PROPOSED DATA HIDING SCHEME

According to the applications, several video compression standards, such as MPEG-2, Motion Picture Expert Group 4 Part 2 (MPEG-4), Windows Media Video 9 Codec (VC-1), Motion Picture Expert Group 4 Part 10 (H.264 AVC) and On2 True-Motion VP6 (VP6) can be employed. Almost all video compressions are block DCT based. In these codecs, every frame is divided into blocks where coding operations are applied on DCT coefficients. However, in H.264/AVC like other DCT block based compression codecs, motion estimation, prediction, entropy coding and compression tricks are applied on each block.

The use of DCT coefficients for embedding the watermark is very challenging in both compressed image and video (such as JPEG and H.264), because compression does not leave much room for watermark location. For the H.264/AVC video codec, the quantized DCT (QDCT) coefficients and the motion vectors are the most used parameters for embedding the information bits. Low, middle or high frequencies QDCT coefficients may be selected to embed the watermark based on the requirements of the application in terms of robustness or fragility. For the embedding process, the choice of the DCT coefficients usually relies on the human visual properties to mask the introduced degradation by the watermark. In our proposed method, robustness is not a priority, thus the high-frequency coefficients are chosen because they introduce less perceptual artifacts. The grey area in Fig.1. shows the locations of high frequency coefficients suitable for embedding the signature.

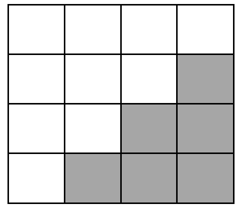

Fig 1. Selected high frequency area in each 4x4 block

In H.264/AVC applying motion estimation, prediction, DCT and quantization results in blocks with value close to one. Since DCT values are quantized, significant number of quantized DCT values (QDCT) are converted to zero. In most blocks there is a last non zero QDCT level (LNZ). Zigzag scanning for each 4x4 block is used for locating LNZ levels. The position of LNZ plays a key role in embedding secret bits in the suggested system. Fig. 2 provides statistics of position of LNZ for different QCIF video tests. This figure illustrates in how many blocks the position of LNZ is equal to P_i , $1 \le P_i \le 16$.

All positions can be used for embedding secret bits but changing low and middle frequency components may cause significant distortion. Thus high frequency levels are used for embedding the watermark. Blue bins in Fig. 2 show the number of LNZ levels in high frequency area.

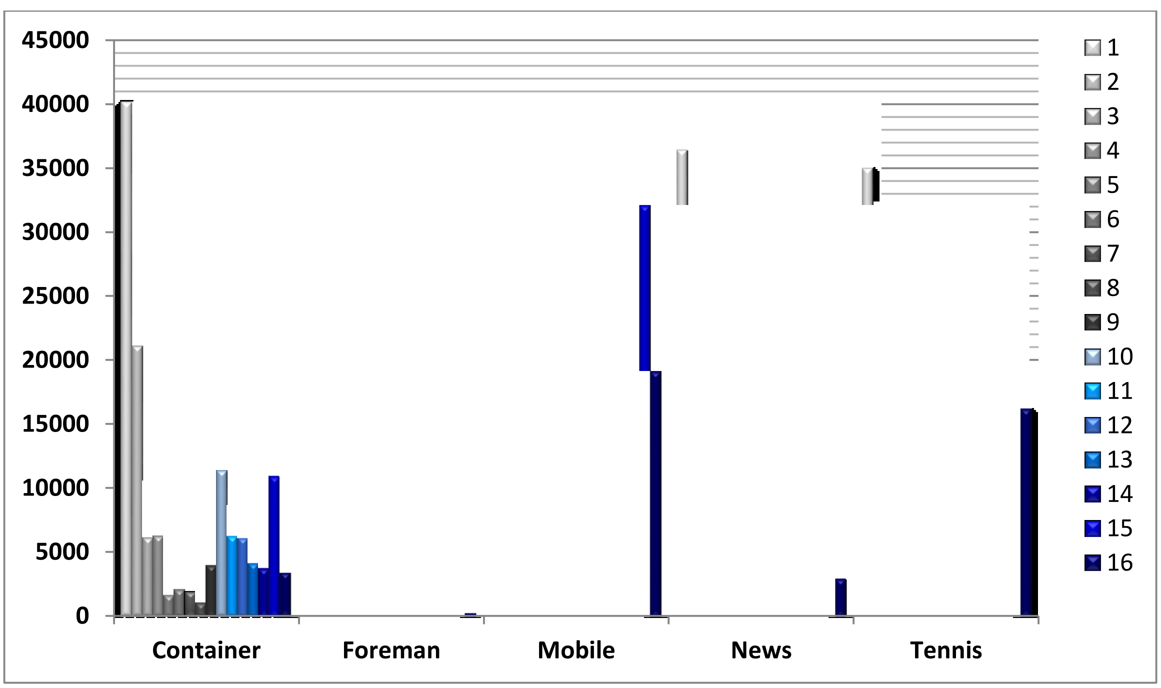

Fig 2. Positions of the last non zero level (LNZ) for five different QCIF test video sequences

A. Embedding

Every block of 4×4 which at least has a high frequency coefficient can be selected for data hiding. *Thr* is defined as a threshold for modification of the LNZ position. More specifically, if the position of the LNZ is greater than *Thr* the block is chosen for embedding and a single bit is embedded in it. The embedding process for each block after the quantization phase is performed by the following steps:

1. To improve the security, encrypt the embedded watermark stream *Ws* by a key called *K*, to form the watermark stream *S*.

   $$S = E(K, Ws)$$

   where *E* is the encryption operation,
2. For each 4×4 block find the position of the LNZ level.
3. If the position is higher than *Thr*, the block has a high frequency element, and is a candidate for embedding, and the embedding process continues. Otherwise return to step 2 for the next block.
4. For each selected block, modify the position of LNZ level (P_i) based on S_i (i th bit of the stream) as follows:

$$P_i' = \begin{cases} P_i & if\ P_i\ is\ even\ and\ \ S_i\ is\ "0" \\ P_i + 1 & if\ P_i\ is\ odd\ and\ \ S_i\ is\ "0" \\ P_i + 1 & if\ P_i\ is\ even, P_i < 16\ \ and\ \ S_i\ is\ \ 1 \\ P_i & if\ P_i\ is\ odd\ and\ \ S_i\ is\ 1 \\ P_i - 1 & if\ P_i\ is\ 16\ and\ \ S_i\ is\ "1" \end{cases}$$

Where S_i is the encrypted watermark bit of i th block.

After the above embedding steps, the block is ready for other steps of the H.264/AVC coding process such as Context-adaptive variable-length coding (CAVLC).

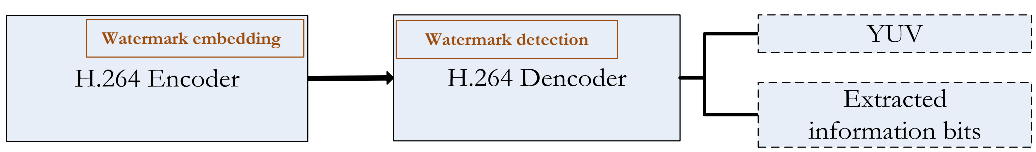

Fig.3. Embedding and detecting flowchart

Fig. 3 shows the embedding and detecting procedures. After decoding the H.264/AVC stream, which includes watermark detection, the YUV file and the extracted secret bits are obtained.

In H.264/AVC, changing the quantization parameter (QP) results in varying the number of non-zero levels in the macroblocks. It is evident that when QP is low, there are more non-zero levels compared to high QP, increasing the embedding capacity.

B. Detecting

The embedded watermark bits are extracted in the decoding process of H.264/AVC where the quantized DCT levels for each MB are entropy decoded. For each block, the following steps result in extracting the embedded bits from each block

1. Find the position of the LNZ level.
2. If the position of LNZ is higher than *Thr*, follow the steps below; otherwise start from step one for the next block.
3. In the selected block, the embedded bit can be extracted as below:

$$S_i = \begin{cases} 0 & if\ P_i^{'}\ is\ even \\ 1 & if\ P_i^{'}\ is\ odd \end{cases}$$

Where S_i is the extracted bit of the i^th selected block in the decoder, and $P_i^{'}$ is the position of the LNZ in the current block.

To obtain the raw watermark stream, we need to decrypt the extracted stream by the encryption key. In general, efficiency, complexity, energy usage and simplicity are more important in the decoder implementation since it is at the client side with limited resources compared to the server side which has more resources. Also, some delay in the encoder is acceptable since it is done only once for a video. So, low complexity and simplicity in implementation are critical points in designing the decoder. One advantage of our proposed technique is its simplicity in implementation at the decoder, allowing it to run for various real-time applications.

3. EXPERIMENTAL RESULTS AND ANALYSIS

In order to verify the performance of the proposed information hiding system, it has been tested on several test video sequences such as Container, Foreman, Mobile, News, and Tennis in QCIF format (176×144 pixels), as shown in Fig. 4. As the watermark is embedded in blocks of 4×4 pixels, the embedding algorithm is independent of the resolution of the video.

The original video streams are obtained by the H.264/AVC reference software version JM12.2 [24], and the proposed method is integrated within the H.264/AVC codec. The most important configuration parameters of the reference software are given in Table 1. The rest of the encoder parameters have retained their default values. Also it is worth to note that in parts A and B *Thr* is fixed at 9, whereas in part C changing the *Thr* itself will be discussed.

Table 1. Configuration parameters of the JM software

Profile	Baseline
Level	3
Intra Period	1
Frame Rate	30
Rate Distortion Optimization	On
Number of encoded frames	100

Capacity is defined as the number of bits embedded in one frame or one second of the video. In this article the capacity is measured and compared with other schemes in terms of embedded bits in a QCIF frame. In an ideal case, there must be no perceptible difference between the watermarked and the original digital contents; i.e. the watermark data should be transparent to the user.

Embedding in the compressed domain such as H.264/AVC changes the bit-rate of the compressed stream. In most cases watermark embedding increases the bit-rate. The bit-rate increase should be in an acceptable range. For example, the increase in bit-rate should not be larger than if the watermark bits are sent out of band.

The trade-off between capacity, transparency and bit-rate is the main challenge for video data hiding in the compressed domain. In an ideal case, a very high capacity and very transparent scheme without any changes of bit-rate are demanded. Practically, achieving all these requirements at the same time is extremely difficult if not impossible. Therefore, depending on the priorities of the data hiding system and the particular application, a trade-off between these properties must be attained.

The rest of this section has three parts. In the first and second parts the capacity, bit-rate increase and transparency of the system are presented. The third part provides comparison with the existing methods.

Fig. 4. Video test sequences

A. CAPACITY AND BIT-RATE INCREASE

The embedding method uses high frequency LNZ level to hide information. Changing QP varies the number of LNZ levels in the high frequency area of blocks, where increasing QP decreases the number of high frequency LNZ and results in more compression. Fig. 5 shows how increasing QP reduces the amount of embedded bits. It is obvious that when the video sequence is more compressed, there is less vacancy for embedding data bits.

Almost any modification in QDCT levels causes the bit-rate to increase. Table 2 presents the original bit-rate (H.264/AVC compression without data embedding), marked bit-rate (H.264/AVC compression with data embedding) and the effect of the proposed embedding algorithm on the compression process in terms of the difference between the original and marked bit-rates. The average capacity is 354.8 bits per QCIF frame and the average bit-rate increase is 0.47%.

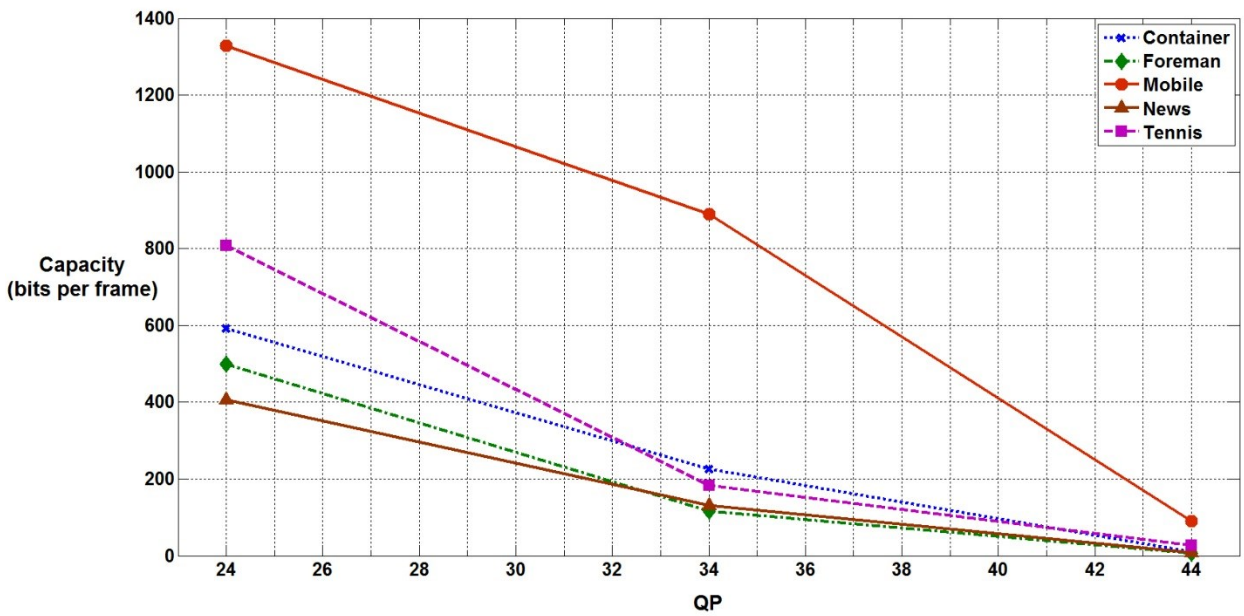

Fig. 5. Capacity and QP for five video test sequences

Table 2. Capacity and bit-rate (kbps) for average of 100 frames for 5 video sequences with different QP

		QP=24			QP=34			QP=44		
		Original	Marked	Difference (%)	Original	Marked	Difference (%)	Original	Marked	Difference (%)
Container	Bit-rate	1146.689	1153.301	0.58	462.9288	467.3568	0.96	157.956	158.28	0.21
	Capacity	591.34			226.81			10.51		
Foreman	Bit-rate	1133.15	1141.042	0.70	429.876	433.3176	0.80	170.1432	170.327	0.11
	Capacity	498.58			116.03			7.01		
Mobile	Bit-rate	3165.281	3174.257	0.28	1570.416	1580.182	0.62	509.6136	510.804	0.23
	Capacity	1328.22			890.17			90.52		
News	Bit-rate	1124.59	1131.948	0.65	508.5576	511.4064	0.56	197.5296	197.7	0.09
	Capacity	405.62			131.16			8.77		
Tennis	Bit-rate	1376.201	1382.681	0.47	449.4024	452.1672	0.62	157.0344	157.3848	0.22
	Capacity	807.72			182.85			27.58		
Average	Bit-rate	1589.182	1596.646	0.536	684.2362	688.886	0.712	238.4554	238.861	0.17
	Capacity	726.296			309.404			28.876		

B. TRANSPARENCY

PSNR can be used as a measure of transparency of the embedding process. While PSNR is a very popular and widely-used evaluation technique, it is known that its correlation to subjective quality measures is not always good, since it reflects only the luminance/chrominance degradations and neglects the behaviour of human perception. Perhaps, a more reliable measuring device is the Structural Similarity Index (SSIM) [25]. While PSNR measures errors between the original and marked image, SSIM measures the structural distortion, luminance and contrast differences between the two frames. The main idea behind SSIM is that the human vision system is specialized in extracting structural information from the viewing field and it is not specialized in extracting the errors. Therefore, a measurement on structural distortion can give a better correlation to subjective impressions. Many different quality assessment techniques can be established from this assumption but Wang et al. suggested a simple and effective index algorithm [25].

SSIM is in the range of 0–1, where 0 shows zero correlation, i.e., the reference frame is entirely different from the target, and 1 indicates that they are identical. Table 3 presents the PSNR and SSIM for 100 frames of each test sequence with three different QP values (QP= 24, 34, 44). The last two rows are the averages of the 5 sequences for PSNR, and SSIM. The overall average results for all three QPs show a quality degradation of 1.4 dB in term of PSNR, and 0.0061 for SSIM.

The extraction process at the decoder is not complex which makes the scheme a perfect solution for real-time applications.

Table 3. Transparency in term of PSNR (in dB) and SSIM for average of 100 frames for 5 video sequences with different QP

		QP=24			QP=34			QP=44		
		Original	Marked	Difference	Original	Marked	Difference	Original	Marked	Difference
Container	PSNR	39.48	36.66	2.82	32.37	31.25	1.13	25.71	25.64	0.07
	SSIM	0.95772	0.95055	0.00717	0.89781	0.89141	0.00640	0.78397	0.78269	0.00128
Foreman	PSNR	39.35	37.86	1.49	32.25	31.80	0.45	25.78	25.68	0.10
	SSIM	0.96926	0.96581	0.00345	0.90413	0.90130	0.00283	0.73757	0.73658	0.00099
Mobile	PSNR	37.90	31.40	6.50	28.73	26.20	2.52	21.09	20.84	0.25
	SSIM	0.98933	0.97832	0.01101	0.92808	0.90482	0.02326	0.67169	0.66242	0.00927
News	PSNR	40.43	38.81	1.62	32.72	32.11	0.61	25.47	25.41	0.06
	SSIM	0.98116	0.97853	0.00263	0.92917	0.92677	0.00240	0.76671	0.76639	0.00032
Tennis	PSNR	38.55	35.59	2.96	31.59	30.64	0.95	26.18	25.99	0.19
	SSIM	0.94827	0.93589	0.01237	0.79508	0.78837	0.00671	0.66747	0.66455	0.00292
Average	PSNR	39.142	36.064	3.078	31.532	30.4	1.132	24.846	24.712	0.134
	SSIM	0.969148	0.96182	0.007326	0.890854	0.882534	0.00832	0.725482	0.722526	0.002956

C. Changing threshold

To show the effects of changing the threshold, *Thr*, capacity and transparency are measured while *Thr* is set to 7, 9 and 11. As table 4 shows, when *Thr* is equal to 7 there are more LNZ positions changing which results in more capacity and more distortion compared to when *Thr* is 9. And when *Thr* is equal to 11, there are fewer LNZ positions changing which leads to less capacity and better transparency compared to when *Thr* is 9. As such, we can say that there is an inverse relationship between *Thr* and capacity, while there is a direct relationship between *Thr* and transparency.

Table 4. Capacity and Transparency for average of 100 frames for 5 video sequences with different thresholds where QP=24

Thr		7	9	11
Container	Capacity	754.96	591.34	334.77
	PSNR	35.44	36.66	38.81
Foreman	Capacity	725.33	498.58	224.22
	PSNR	36.76	37.86	39.2
Mobile	Capacity	1492.66	1328.22	1060.56
	PSNR	28.08	31.4	35.68
News	Capacity	549.64	405.62	311.16
	PSNR	37.6	38.81	39.15
Tennis	Capacity	993.76	807.72	709.04
	PSNR	34.93	35.59	36.45
Average	Capacity	903.27	726.296	527.95
	PSNR	34.562	36.064	37.858

D. Comparison with the Existing Methods

As each data hiding method has its own special properties under different conditions, it is difficult to provide a very accurate comparison. Nevertheless the proposed method can be compared with some existing methods as explained below:

[8] proposes an information hiding algorithm based on intra-prediction modes and matrix coding for H.264/AVC video stream. [8] improves the data hiding algorithm proposed by Hu et al. [26]. [8] and [26] provide low distortion; however their capacity is very low, and also the bit-rate increase is considerable. [27] introduces a high capacity scheme which increases the bit-rate dramatically. [9] enhances [27] in terms of capacity and bit-rate increase, but it does not provide general results, and only compares its scheme with [27]. The original capacity, PSNR and SSIM (without embedding) are not reported in [9] so it is really difficult to know the efficiency of the system. Mansouri et al. [28] present a high capacity method whereas the bit-rate increase is considerable and transparency is not reported.

As Table 5 shows, simulated outcome in a wide range of QPs, 24–44. The capacity of the proposed method is very high, and although [27] provides more capacity, but bit-rate increase in [27] is about 7 times more than the proposed method. [29], [30] provide good capacity but bit-rate increase is 5 and 8 times more than ours. Also

[29] distorts the image by about 6.5dB which may not be acceptable for many applications. [30] reduces the quality of the frames by about 3.7dB which is about three times more than the proposed algorithm.

Our suggested scheme presents the best bit-rate increase, less than half of the best reported method. Based on SSIM results, our proposed method is very transparent. However, since other schemes do not provide SSIM, comparison in terms of PSNR is also provided in the table.

Table 5. Comparison in terms of capacity, bit-rate increase and transparency

Method	QP	Capacity Bits per frame	Bit-rate increase (%)	PSNR degradation	SSIM degradation
[8]	Not reported	33 – 42	1.6	0.02	Not reported
[26]	28	25 –40	2.8	0.02	Not reported
[27]	28	840	3.6	2.1	Not reported
[9]	18 – 43	Not reported	1.68	~ 6	Just marked SSIM is reported
[28]	Not reported	274	1.1	Not reported	Not reported
[29]	Not reported	764	3.8	6.5	Not reported
[30]	Not reported	766	2.3	3.7	Not reported
Proposed	24–44	355	0.47	1.4	0.0061

4. Conclusions

To design an efficient and low complexity method, the embedding and extracting of watermarks are integrated with the coding and decoding routines of H.264/AVC. The information hiding system utilizes position of the last nonzero (LNZ) level of QDCT block to embed the information bits. To assure transparency to the human visual system, the high frequency levels are changed. Changing just high frequency levels can guarantee a high PSNR, SSIM and slight bit-rate increase after the watermark embedding.

As the extraction procedure is not complex, the proposed technique is an excellent solution for real-time applications such as broadcasting. Experimental results on several test sequences prove that the proposed approach can realize blind extraction with real-time performance, delivers very high capacity and low distortion and also it keeps the bit-rate increase by about 0.005.

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