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RECENT METHODS AND TECHNIQUES IN VIDEO WATERMARKING AND THEIR APPLICABILITY TO THE NEXT GENERATION VIDEO CODEC

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ABSTRACT

High efficiency video coding (HEVC) is the newest video coding generation of the ITU-T and ISO/IEC, which first appeared in January 2013. It has the advantage of reducing the bit rate by as much as 50 % when compared to H.264 while maintaining the same visual quality. In the last decade, authentication and copyright protection methodologies have become one of the essential items in order to protect video contents by embedding within an efficient video codec. Thus, the objective of this paper is to revise recent developments in the area of watermarking techniques for video coding schemes and their applicability to the new Standard HEVC. The results of this study provide motivation to achieve a higher embedding capacity and higher compression performance for HEVC compared to H.264/AVC especially, for low bit-rate coding.

Keywords: *Digital Watermarking, Hiding Data, Video Watermarking, Video Coding, HEVC*

1. INTRODUCTION

This High-speed interactive network applications and recent technological achievements with a variety of end user entities have developed the manner in which digital data is distributed. A wide range of video applications, easy access to video content and the possibility to make unlimited copies without loss of considerable fidelity have motivated the need to protect this material. Consequently, in the last decade, video compression standards have been improved to provide more compressed data along with better visual quality resolution. As a result, providing a security method with higher efficiency coding is a priority demand. Video digital watermarking integrated with these standards is a technology that can serve this purpose. A large number of video watermarking techniques have been proposed to embed copyright marks and other information in digital video, which can later be extracted or detected.

Digital video is a sequence of still images or frames. However, video watermarking techniques need to meet other requirements than those required in image watermarking schemes, such as video coding technologies, redundancy between sequences of frames and some particular video attacks [1]. In addition, video watermarking techniques that use coding structure techniques as a core component in the watermarking schemes are the primary target for the goal of integrating watermarking and compression to reduce the complexity of video watermarking processing. Therefore, integrating watermarking requires an optimal implementation of the watermarking framework at the encoder to reach that goal.

Despite the success of these video codecs such as MJPEG2000, MPEG-2 and H.264 for the video coding and video watermarking, a new standard known as HEVC [2] with higher compression efficiency, is poised to replace them. In addition, the HEVC digital video has become more widespread in different applications; therefore the industry will need appropriate methods to protect and secure their productions based on HEVC.

The main contribution of this paper is to evaluate the current digital video watermarking techniques used in previous video coding, analysis of their performance and the possibility of improving these existing methods to integrate with HEVC standard.

In section 2, we evaluated the basics of video watermarking, and video watermarking techniques. In Section 3, we briefly discuss recent development

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in video watermarking based on coding structures techniques. Basics of HEVC encoder are explained, and applicability of different watermarking techniques in HEVC is also described in this section. Finally, possible future research directions are discussed for optimizing the existing different watermarking techniques integrated with HEVC standard.

2. DIGITAL VIDEO WATERMARKING

2.1 Overview on Digital Watermarking

Digital watermarking has been presented as a key to the problem of copyright protection of multimedia data in the next generation networks [3]. Essentially, nowadays with a broad range of video applications, Multimedia transmissions over wireless channels and the Internet requires that multimedia resources must be protected. Thus, video coding integrated with digital watermarking techniques can be efficiently employed to achieve this goal. However, digital video watermarking has many aspects that must be considered during the design of any digital video watermark schemes such as imperceptibility, robustness, capacity, complexity, synchronization, bit-rate control and error drift [4] [5] [6] [7].

A watermarking system consists of two main components: a watermark embedding unit and a watermark extracting unit as shown in Figure1. The embedding unit adds the watermark component to the host data. The output of the embedding unit is the watermarked data. Attackers intend to do one of the following illegal actions such as modifying, copying, destroying or removing the watermark from the host data.

Figure 1: Main Units of Watermarking

2.2 Video Watermarking Techniques

According to the work of watermarking embedding, video watermarking techniques are divided into three main groups or classifications, namely spatial domain, frequency domain and bit-stream domain as shown in Figure 2. Each group applies different methods. In this section, a brief review is covered with the current video watermarking techniques based on their watermarking domain.

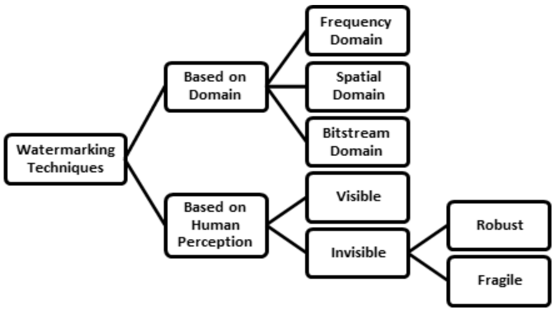

Figure 2: Classification Of Watermarking Techniques

2.2.1 Spatial domain watermarking

The spatial domain watermarking techniques embed the watermark by modifying the pixel positions or pixel values of the host video. The main advantages of using this technique are the small time complexities and simplicity of implementation. However, these techniques have some disadvantages in providing robustness and meeting imperceptibility requirements [8].

Many methods for developing watermark techniques in the spatial domain have been proposed such as the Least Significant Bit (LSB) and Spread Spectrum Signal Correlation (SSSC) techniques. In the LSB method, the host frame is used to insert the watermark. The positions of the pixels are modified by generating a pseudo-random number based on a secret key. Another method in the spatial domain is SSSC. This method is based on adding a pseudo-random noise pattern to the luminance value frames in the spatial domain, and the correlation between the noise pattern and possibly watermarked video for each frame is computed. If the correlation exceeds a certain threshold then, the watermark is detected [9].

2.2.2 Frequency domain watermarking

The majority of video watermarking techniques have been used in the frequency transform domain in order to overcome the main disadvantages of the spatial domain. Further, analysis of the bands in the frequency domain is a prerequisite to enhance watermark robustness and imperceptibility. However, these techniques have some disadvantages in terms of complexity.

A number of transforms are used to transfer from the spatial to a frequency domain. For example, the discrete Fourier transform, discrete cosine transform, discrete wavelet transform, and hybrid transforms that are discussed in this section. In addition, a review is given of some proposed methods that have been applied to developing watermark techniques in the frequency domain.

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- **Discrete Fourier Transform**: A Discrete Fourier Transform (DFT) is performed on the original video data. The watermark is embedded in optimal selected frequency bands of the DFT. An inverse Discrete Fourier Transform is performed onto the watermarked frequency domain to reconstruct the watermarked video [10]. For example, in [11] the authors proposed a 3D DFT-based robust watermarking scheme in which the watermark is embedded in 3D DFT coefficient blocks of the video scene. This technique enhances the robustness of the watermarking scheme against some common attacks. However, due to the complexity factor, it would be difficult to realize practically. To solve this problem, the authors in [12] proposed a video watermarking method based on the 1D DFT and Radon transform and an adaptive embedding approach to reducing the complexity. However, due to security issues, it would not be resistant to some types of attacks. Elbasi et al. [13], proposed a watermarking scheme based on a stochastic process, the Hidden Markov Model (HMM), and Artificial Neural Networks (ANNs). The proposed scheme decomposed a visible watermark into sub-images and embedded them into video frames. The method used the HMM model to select the best time for embedding and applied it to a dependency among the different parts of the watermark. Meanwhile, the neural network decides the best transform domain for each frame. In the detection unit, the watermark is extracted, in the same way, as the embedding phase and compared with an individual threshold. If it is detected, then all the parts are combined to recreate the original watermark. This method is robust against attacks. However, the computational cost is high.
- **Discrete Cosine Transform**: The Discrete Cosine Transform domain (DCT) is a very promising technique used in video coding and used in many watermarking schemes. In this subsection, some proposed methods are discussed. The first method presented is that proposed in [14], where the watermark is embedded in the low band that has the perceptually significant portion of the Human Visual System (HVS) in order to be resistant to the compression process. However, due to the capacity factor, it would be difficult to extend. In [4], the author proposed a watermarking scheme based on the motion vector technique in MPEG. The DCT coefficients for intra-frame and non-intra-frame are modified according to the values of the motion vectors. This method could achieve robustness against image cropping operations and MPEG compression. However, it is vulnerable to format conversion. In another study [15], an optimal H.264 watermarking scheme was proposed. The Practical Swarm Optimization (PSO) approach has been applied to find optimal integer DCT coefficients of the I-frame for embedding the watermarking information based on Dither modulation. As mentioned by the authors, the I-frame is a useful criterion for applying the embedding watermarking information, and also the PSO-based approach is used to reduce complexity.
- **Discrete Wavelet Transform**: The Discrete Wavelet Transform (DWT) provides a promising hope for image and video processing applications because of its flexibility in representing images or frames and its ability to take into account human visual system characteristics [16]. A wavelet transform decomposes an image into a set of different resolution subframes, which correspond to the various frequency bands. That gives a better representation of frames with localization in both the spatial and frequency domains. This advantage is desirable in a compression standard, and it is not possible in both Fourier and Discrete Cosine Transforms that give good localization in one domain at the expense of the other [16]. The watermark is inserted into the optimal selected DWT sub-bands combined with motion vector methods. An inverse DWT is performed on the watermarked magnitude domain to reconstruct the watermarked video. Several methods use the DWT to design watermarking schemes. For example, some researchers work on a frame by frame embedding approach and select the optimal watermark embedding positions using genetic methods and/or artificial neural networks as in [17] and [18]. Other researchers have presented another approach based on 3D DWT. The 3D decomposition-based methods overcome issues such as the de-synchronization attack, video format conversion, and video collusion. However, the computational costs are high for all of these methods that work without considering the motion element of the sequence during watermark embedding, thus causing flicker distortion. As a solution to this problem, the authors in [1] proposed a motion compensated temporal filter with 2D DWT to

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improve video watermarking schemes by offering a generalized motion compensated 2D+t+2D framework for watermark embedding. As mentioned by the authors, the proposed method shows better embedding distortion in terms of PSNR and flicker(flicker is a perceptual attribute of displays) metric. Recent work Wang et al. [19] proposed a method based on two stages. Firstly, obtain one level of DWT on a block of DCT coefficients for the compressed video. Secondly, embed the watermark into histogram bins of frames in the one-level DWT domain. The video data is partially decoded to obtain block discrete cosine transform (DCT) coefficients, which are subsequently used to construct a one-level DWT. This method reduces the computational cost and meets the real-time requirement in the compressed domain [19]. Some recent methods have been proposed based on hybrid transforms such as the DWT and SVD in [20] or DWT, DFT and the Singular Value Decomposition DWT- DFT-SVD domain in [21]. In [21] The watermarked video is obtained by inserting the singular values of DWT+DFT transformed sub-bands into singular values of DWT+DFT transformed sub-bands of reduced video frames. The method applies the particle swarm optimization technique to identify the robust pixels into which the watermark is to be inserted. As mentioned by authors, the PSNR values for the watermarked video are between 45 dB and 50 dB and the maximum correlation resulted in 0.9998. However, the computational cost of this method is still high.

2.2.3 Bit-Stream domain watermarking

The watermark is embedded into the compressed video bitstream. The advantage of this technique the computational cost is low. However, the disadvantage is that the compressed bit-rate constrains the size of the watermarked data. The strength of the embedded watermark is limited by the error rate of the decoder side, and the embedding process is constrained by the coding standard and the video compression method. The authors in [5], presented a video stream by inserting the watermark in the least significant bit form of Variable Length Coding (VLC) entropy coding.

Fridrich et al. [22], proposed a watermarking scheme for JPEG. This system works based on the LSB watermarking technique. The AC coefficients of the DCT are paired, and the watermark inserted in the least significant bits of individual bytes using VLC code based on a priority mode. These schemes take advantage of the video compression standard without re-encoding and full decoding. They have less complexity and a higher capacity for embedding the watermark. However, their disadvantages are that the behavior with noisy channels is worse, and the watermark information can be corrupted by adding random bits in the VLC code.

2.3 Recent Developments in Video Watermarking Based on the Coding Structure Technique

Video watermarking techniques that use the coding structure method, as an essential component in watermarking schemes are primarily targeted with the goal of integrating watermarking and compression standards. The integration is used to reduce the complexity of the video watermarking processing, and this integrated watermarking requires an optimal implementation of the watermarking framework for the encoder to reach the goal. In this section, the combined schemes of watermarking and compression standards are discussed by using recent development methods. Figure 3 at the end of the paper illustrates a generic system for video watermarking based on coding structure techniques [23].

2.3.1 Watermarking techniques for MPEG

The primary component of the Moving Picture Experts Group (MPEG) standard is the motion vector compensated coding [24]. A picture compressed using its pixels as a reference is termed as an intra-frame, also named an I-frame or reference frame. A reference frame is used for compression of a collection of upcoming frames called inter frames or P-frames. Another type of frame called a bi-directional frame or B-frame is compressed using information from both p-frames and I-frames [25]. I-frames are divided into blocks that are transformed by DCT function, then passed to a quantization process, zigzag scan, run-level coding and entropy coding. P and B frames are motion compensated, and the residual prediction error signal frames are divided into blocks[24]. Different frequency domain techniques have been proposed to embed watermarking such as embedding a watermark in the DCT coefficients of I-frames, embedding a watermark based on the motion vector and embedding a watermark in the DCT coefficients of P or B frames. For example, in [4], the author proposed a watermarking scheme based on the motion vector technique in MPEG. The DCT coefficients for intra-frame and non-intra-frame are modified according to the values of the motion vectors. This method can achieve

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robustness against image cropping operations and MPEG compression; however it is vulnerable to format conversion. Su et al. [6], proposed real-time video watermarking technique based on embedding data in a variable length coding (VLC) entropy coding for MPEG-2 with control of the bit-rate. In [26], an adaptive real-time video watermarking scheme is implemented by modifying the relations of equal quantization step DCT coefficient pairs. However, both methods are not robust against specific attacks, for example, downscaling and transcoding. In addition, these methods are not resistant enough against video processing attacks and geometric distortion attacks. Vassaux et al. [27], embeds the watermarking into quantized DCT coefficient blocks of MPEG4. This method modifies some predefined pairs of quantized DCT coefficient blocks based on spread-spectrum techniques. Dividing the frame into blocks of equal size, a binary sequence is generated using a secret key and then added to the frame [27]. Zhang et al. [28], proposed a video watermarking method based on Motion Vectors (MVs). According to the HVS quality measurement, the motion vector value is optimized to select the best value to embed the watermark information. Then, different watermarks are embedded in the various parts of the motion vector. This technique enhances the robustness of the watermarking scheme [28]. Yan et al. [29], implemented a watermarking technique based on the game of life approach to scrambling the MPEG-4 motion vector adaptively. This work makes the watermarking method and the video coding integrated, and they achieve robustness against a compressed attack [29].

2.3.2 Watermarking techniques for the H.264

The H.264 standard is the codec with the highest performance in video data compression. In contrast to MPEG-2, H.264 offers almost double the compression rate for the same video quality [30] [31]. There is a considerable amount of interesting literature on different watermarking techniques [31] [32], [33] [34], [35], [36], [37], [38], [15], [39], [7], [40], [41], and [42] for H.264. A watermarking can be implemented in DCT Coefficients, in the motion vectors, in the entropy-coded part, or in a combination of the above. However, most of the reliable and robust watermarking techniques are applied in the DCT domain only [32] because in DCT domain, the error introduced by watermarking is not propagated into other macroblocks [7]. The H.264 standard design has different scheme units from other previous video standards such as MPEG. Firstly, the DCT transform is applied on 4x4 blocks instead of 8x8 or 16x16 blocks. Secondly, the integer DCT used in H.264 differs from the other DCT transformations used in other standards [30]. In addition, the advances in multimedia technology with the variety of end-user entities has given rise to a new coding technique called Scalable Video Coding or H.264/SVC, which is an extension of the H.264 standard. This extension uses the scalability approach to adapt the video bit stream to a different end users and channel capacities [42]. Hence, a considerable amount of literature described works to develop watermarking techniques based on new challenges for watermarking in H.264. Recent works are discussed in this subsection. For example, in [31], a skipped macroblocks approach is used to embed a watermark in H.264 macro-blocks. For authentication purposes, a hash function is utilized. The scheme is time efficient, but not robust against a compression attack. In [36], a real-time watermarking technique has been proposed. The method selects the optimal sub macro block I-frames for embedding the watermark, and to increasing watermark robustness the bit-rate is controlled within a range. In this way, a little complexity is achieved. In [37], a watermarking scalable video coding framework is proposed. This work focuses on embedding the watermark in the intra-coded macroblocks of the base resolution layer in H.264/SVC. Each macroblock is coded by using both intra or inter-frame coding, and the residual error. Then the watermarked base layer representation is used for predicting the enhancement layer, and to provide a watermarked bit stream for different end users. In [38], a watermarking technique has been proposed according to detecting motion coherent video regions. The motion coherent regions are detected based on the MVs of the I-frames. Then the motion coherent regions are classified into block clusters, and sufficient block clusters are used for embedding the information watermark. This technique enhances the robustness of the watermarking scheme against collusion attack with a low complexity. In [15], an optimal H.264 watermarking scheme was proposed. The Practical Swarm Optimization (PSO) approach has been applied to find optimal integer DCT coefficients of the I-frame for embedding the watermarking information based on Dither modulation. As mentioned by the authors, the I-frame is a proper criterion for applying the embedding watermarking information, also for less complexity using PSO-based approach. Stutz et al. [39], proposed a structure-preserving H.264/CAVLC watermarking scheme. The Context-Adaptive Variable-Length

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Coding (CAVLC) is a mode in H.264, which is computationally less expensive with a drawback in compression performance. The Motion Vector Difference (MVD) and adaptive bit substitution methods have been applied to embed watermarking information in macroblocks that have changed in MVD. As mentioned by the authors, the detection process works in the pixel domain and thus is robust to video format conversion. In [7], a compressed domain watermarking scheme was proposed to reduce the error propagation in H.264 macro-blocks. The system was designed according to Compression Influence Values (CIVs) techniques that are computed based on prediction dependency relationships amongst the various macro-blocks in video frames. Macro-blocks having the lowest CIVs are selected to embed the watermarking information. As mentioned by the authors, the reducing error drifts during compressed domain watermarking is achieved with less complexity. Bao et al. [40], proposed a watermarking scheme based on Region of Interest (ROI) in H.264/SVC. The watermark is embedded only in the ROI, where the most valuable contents of the video such as moving objects are protected, and the background is not changed. Thus, this technique enhances the robustness of the watermarking scheme against some common attacks with less complexity [41]. Ko et al. [41], built an error detection system based on fragile watermarking for H.264. The plan is designed to increase the error detection ratio. If the channel is attacked, errors will corrupt the watermark information because the watermark is fragile. For this reason, the decoder can detect the errors in macro-blocks easily since the fragile watermark is inserted into them [41].

3. WATERMARKING FOR THE HEVC

3.1 Overview On The HEVC Standard

HEVC is the newest video coding scheme of the ITU-T and ISO/IEC as of January 2013. It has the advantage of reducing the bit rate by as much as 50 % when compared to H.264 while maintaining the same visual quality [2]. For this reason, the HEVC video coding embedded with a suitable watermark is a priority objective today. Previous sections have already discussed recent developments in video watermarking techniques for various video coding schemes. This section gives an overview of HEVC, and finally the section discusses the applicability of these techniques in HEVC. The results will serve both researchers in this area, and system designers aiming to gain robust techniques and reduce computational complexity.

The central architecture of HEVC is based on the same design as in the H.264 standard. Both methods utilize the following steps; a prediction step, a transformation step, a quantization of prediction residues step, and an entropy coding step [43]. The significant compression ratio improvement of HEVC compared to H.264 is achieved by adding new efficiency coding tools such as an adaptive loop filter, the sample adaptive offset, and a motion merge technique [44].

The core unit of HEVC is the Coding Tree Unit (CTU) instead of the macro-block in H.264, which divides into smaller Coding Units (CUs) based on the frame partitioning structures. In addition, the CU splits into different block sizes, ranging from 4×4 to 64×64 [45]. Furthermore, The HEVC supports variable-size blocks selected according to the needs of encoders in terms of buffer size and computational requirements. The support of larger blocks than in previous standards is particularly beneficial when encoding high-resolution video content [2]. A generic block diagram of the HEVC encoder is shown in Figure4.

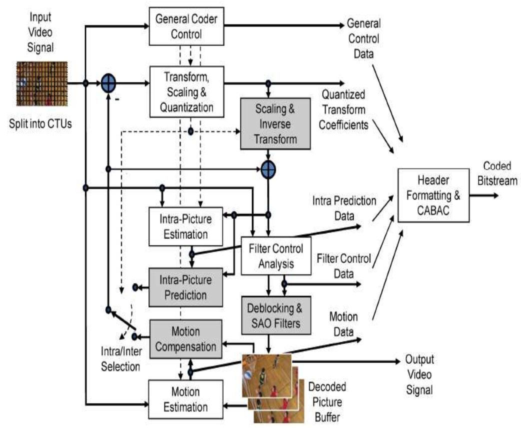

Figure 4: HEVC Video Encoder Block Diagram [2]

The current design of HEVC model (HM14.0) introduced the concept of the coding tree structure. A frame divides into Largest Coding Units (LCU), and each LCU can be further split into sub-coding units through a recursive quad-tree structure. Leaf code units can also be further partitioned into Prediction Units (PUs) of size $2N \times 2N$ or $N \times N$ with size (from 4×4 to 32×32). Each PU works as an independent, primary entity for transforming them using transform units. In intra coding, the definition of Transform Units (TU) nested within PUs allows the TU size to change independently of the size of the

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PU in which it resides [46] [47]. From the leaf node of the PU, the TU can be split into four sub-TUs (from 32×32, 16×16, 8×8 and 4×4) recursively until the minimal allowable of Residual Quad-Tree Depth (RQT-Depth) is achieved.

In the HEVC intra coding, for one $N \times N$ PU where N have a value from 32 down to 4, there exists only one TU of size $N \times N$, whereas four 32×32 TUs are used when N = 64. The HEVC applied two types of transforms: the Integer Discrete Sine Transform (Int-DST) and the integer Discrete Cosine Transform (Int-DCT). The Int-DST is used for TUs while the DCT is utilized for TUs with sizes from down to [48].

3.2 Watermarking Techniques Applicable To The HEVC Standard

In recent works [49] [50], the complexity of the HEVC codec scheme has been discussed. As mentioned by the authors, a higher efficiency video coding is achieved at the cost of computational complexity. Therefore, the new challenge for high-efficiency video encoding designers poses how to improve using a coding efficiency tool, without additional complexity.

Moreover, as HEVC digital video becomes more prevalent, the industry will need appropriate copyright protection and authentication methods in the near future. So the development of new methods is required to integrate robust watermarking techniques for different profiles of HEVC. However, a watermarking requirement adds another challenge to the video watermarking encoding designers. Therefore, in order to give the reader a clear idea of the state of the applicability of different watermarking techniques in the HEVC standard, Table1 at the end of the paper summarizes recent selected watermarking techniques versus applicability and limitations used in HEVC. Furthermore, Table1 presents a comparative analysis according to the robustness, capacity, imperceptibility and computational cost of different watermarking methods.

3.3 Invisible watermarking for the HEVC

To facilitate the classification of the different methods, we can categorize them based on the position where the watermarking data insert during the video coding.The four options are: before encoding, after quantization, during entropy coding and encoding process. Figure5 at the end of the paper illustrates a classification of watermarking techniques based on HEVC structure. According to option 2 in Figure5, we can cite the intelligent proposal of Chang et al. [53]. The proposed developed a new technique to categorize blocks based on certain intra prediction mode without any error propagation in the I-frames HEVC streams. The proposed method embeds bits from 4×4 to 32×32 transform blocks size of the HEVC. The experimental results for the PSNR (Peak Signal to Noise Ratio) and the embedding capacity for different bit-rates are given in Figure6 for comparison between those techniques. About the bitrate, the proposed method achieves higher embedding capacity and higher compression performance compared to H.264/AVC [54] for low bit-rate video error free coding. However, it is not robust against noisy channel or signal processing attacking.

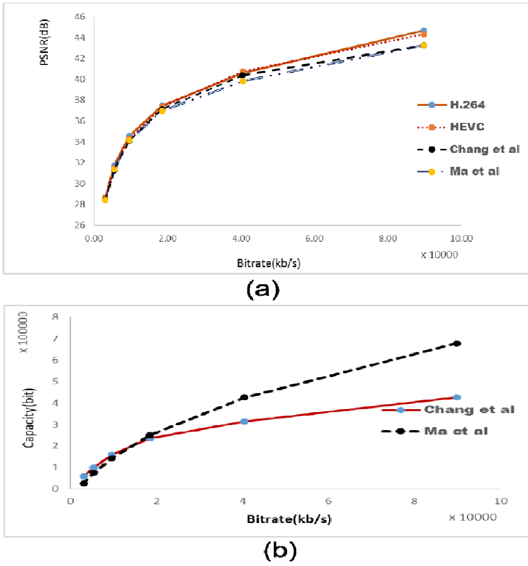

Figure 6: Objective Data Hiding Performance Evaluation (a) PSNR vs. Bit-Rate and (b) Capacity vs. Bit-Rate Plots for Tested Techniques on Video Test Named PeopleOnStreet with Size 2560x1600

4. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

Based on our literature, it can be deduced that the watermarking methods designed for those current video coding standards cannot be directly applied to the new video coding HEVC. Therefore, the HEVC structure has to be taken into account for designing new HEVC watermarking schemes. The improved methods can achieve a higher embedding capacity and higher compression performance compared to previous video coding standards such as H.264/AVC video coding.

The limitations of watermarking methods should take into account in any future research works. Refer to the magic triangle shown in Figure7, it can be seen the trade-off between the coding efficiency tool, watermarking requirements, and scheme

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simplicity that, are required to implement the HEVC watermarking.

The possible future research directions can be outlined as follows:

- Developing watermarking scheme based on ROI in HEVC such as the idea of the proposed in [38] [40] [51] for H.264;
- Developing watermarking scheme based on reduced computational complexity of the system using optimization approaches, like PSO-approach or ANNs [13] [15];
- Modeling the transmission channel error and its influence on the watermark robustness for HEVC applications such as in [41];
- Developing real-time watermarking authentication schemes by using bit-stream-domain watermarking for the HEVC such as in [19] [43];

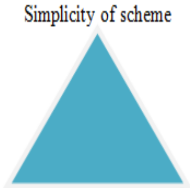

Figure 7: Required Trade-Off between Coding Efficiency Tool, Watermarking Requirements, and Scheme Simplicity.

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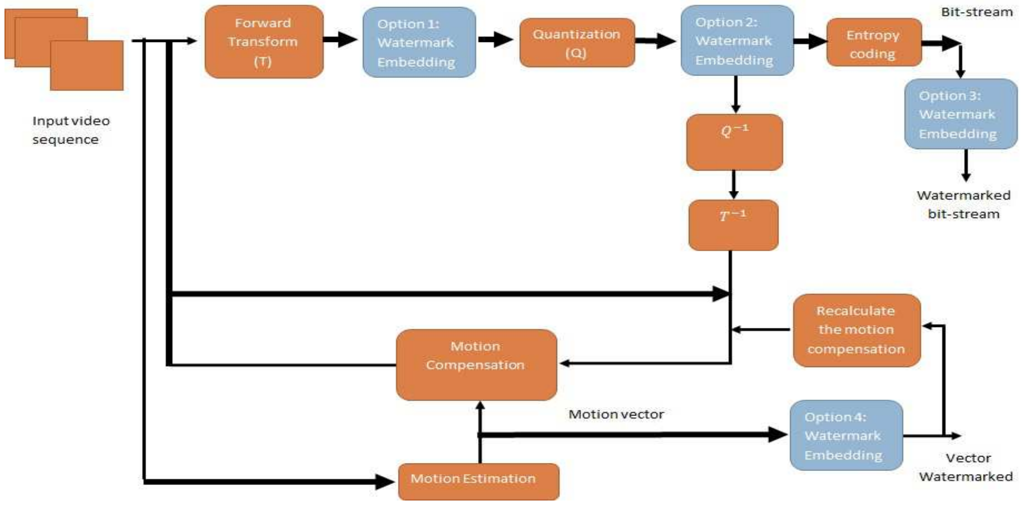

Figure 3: Generic Scheme For Video Watermarking Based On Coding Structure Techniques [23]

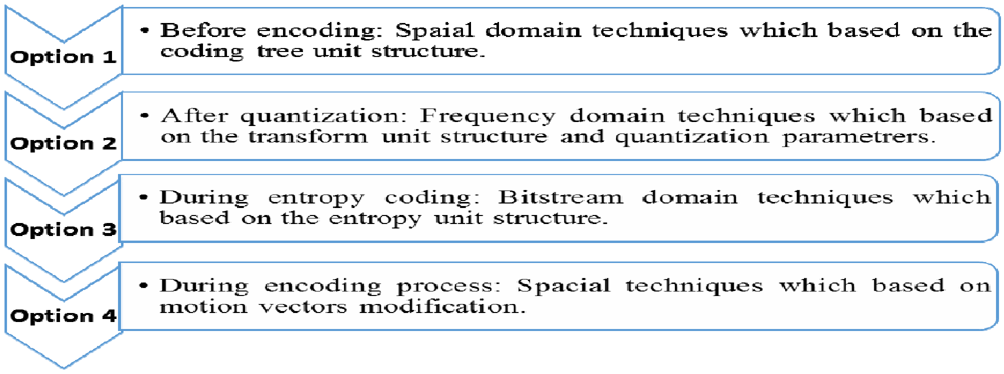

Figure 5: Classification Of Watermarking Techniques Based On Hevc Coding

Table 1: Summary Of Recent Selected Watermarking Techniques Versus Applicability And Limitations Used In Hevc Standard

Technique or Method	Domain	Primary tool	Applicability in HEVC	Associated reference	Main Features	
					Advantages	Disadvantages or Limitations
SSSC	Spatial/Frequency	Algebraic/ Transformed	Yes	[9] [12] [14]	Less complexity	Less robustness
VLC	Entropy coding	Algebraic	Yes	[4] [5] [20]	Less complexity	Less robustness
3D DFT	Frequency	Transformed	No	[10]	DFT none used in HEVC	
DWT- DFT-SVD	Frequency	Transformed	No	[19] [21]	DWT none used in HEVC	
Error Detection Model	Frequency	Transformed	Yes	[41]	Less complexity	Imperceptibility problem
ROI	Spatial/Frequency	Algebraic/Transformed	Yes	[38] [40] [51]	Imperceptibility	Less capacity
Optimization	Spatial/Frequency	Algebraic/Transformed	Yes	[13] [15]	Robust	Less capacity and more complexity
Real-Time	Spatial/Frequency	Algebraic/Transformed	Yes	[26]	Less complexity	Less robustness and capacity
(HVS) Model	Spatial/Frequency	Algebraic/Transformed	Yes	[33] [52] [53]	Imperceptibility	Less capacity