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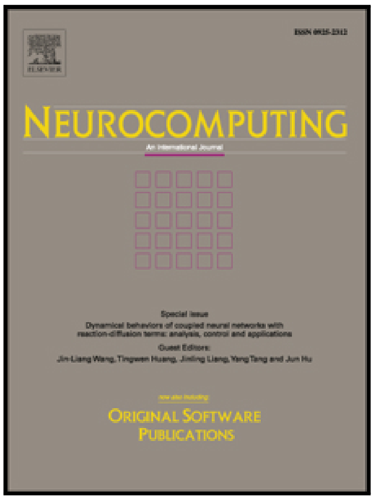

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Video Steganography: A Review

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Abstract Video steganography is becoming an important research area in various data hiding technologies, which has become a promising tool because not only the security requirement of secret message transmission is becoming stricter but also video is more favored. In this paper, according to the embedded position of secret message, video steganography is divided into three categories: intra-embedding, pre-embedding and post-embedding. Intra-embedding methods are categorized according to the video compression stages such as intra-prediction, motion vectors, pixels interpolation, transform coefficients. Pre-embedding methods are manipulated on the raw video, which can be classified into spatial and transform domains. Post-embedding methods are mainly focused on the bitstreams, which means the procedure of embedding and extraction of video steganography are all manipulated on the compressed bit stream. Then we introduce the performance assessment for video steganography and the future popular video steganography including H.265 video steganography, robust video steganography and reversible video steganography. And challenges are finally discussed in this paper.

***Keywords*: *Data hiding; Video steganography, Visual quality, Embedding capacity, Robustness, Intra-embedding, Pre-embedding, Post-embedding*.

1. Introduction

Video steganography is a branch of data hiding, which is a technique that embeds message into cover contents and is used in many fields such as medical systems, law enforcement, copyright protection and access control, etc. [1].Since human visual system are less sensitive to the small changes of digital medias, especially for digital video, video steganography is a technique which hides message into a video and conceals the fact of the transmission. And it has become more popular recently because of two main reasons: Along with the fast development of computer applications, the security problem in information field is becoming more and more serious. Video is an electronic medium which can be more eligible than other multimedia because of the booming of powerful sharing/transmission tools of digital video contents and its size.

Three main important factors should be considered in any successful steganography system: imperceptibility, robustness and embedding capacity [2].

Imperceptibility is closely related to the safety of steganography methods concealing the secret message into the embedded video. The high imperceptibility means a low modification rate and good visual quality of the embedded video [2]. And the steganography algorithm that contains a high imperceptibility will reduce attacker suspicion of finding hidden message and will be quite difficult to detect by steganalysis tools, and any distortion to the cover data after the embedding process occurs will increase the attention of attackers [3]. In video steganography, imperceptibility is the perceptual similarity between the original and embedding video, and evaluated as a visual distortion caused by embedding modifications. To improve the imperceptibility, many video steganography methods have used lots of methods such as quantization transform coefficients [17-23], predictions modes [15-16], and motion vectors [56-65], etc. to enhance the performance of imperceptibility.

Robustness is the second prerequisite which measures the steganography method's strength against attacks in video steganography. The reason of the consideration of robustness is that the embedded message sometimes cannot survive from various intentional or unintentional attacks, such as network transmission, packet loss, video clipping and scaling operations [4]. And the figures 1-2 present the intentional and unintentional attacks, respectively. The algorithm is robust when the receiver can extract the secret message correctly without any errors. To improve the robustness, many techniques have been made in video steganography, such as BCH code [18], secret sharing [20-21], and histogram distribution constrained [72], etc. The robustness is critical to the quality of the video steganography method, as the literature in [102] depicted, high efficient steganography algorithms should be robust against both signal processing and adaptive noises. To improve the evaluation precisely, the survival rate is that all the embedded bits are divided by the embedded bits retrieved without error is used to measure robustness [3].

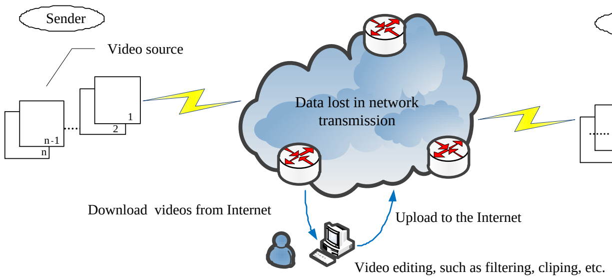

Fig. 1 Unintentional attacks

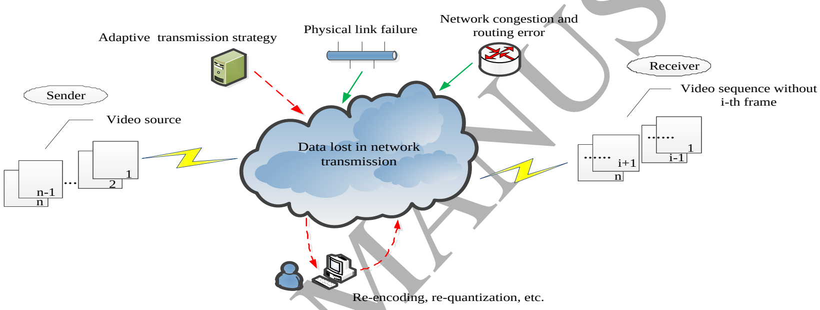

Fig. 2 Intentional attacks

Embedding capacity is the third fundamental prerequisite and is defined as the sum of secret message that can be embedded into the digital video. The higher embedding capacity means the more secret message can be embedded. However, higher embedding capacity could lead to the higher risk for the decrease of visual quality and increment of bit-rate for the embedded video. In traditional steganography methods, embedding capacity and imperceptibility of embedded video are inter conditioned, and the imperceptibility is affected by embedding capacity. So the imperceptibility of video steganography should be taken into account when the method has higher embedding capacity. To increase the embedding capacity with the high imperceptibility, many state-of-the-art technologies have been presented in the steganography methods, which are based on H.264 and respectively utilized the combination of the prediction modes and DST coefficients [19-21], pixel interpolation [52], motion estimation [57], etc. During the evaluation of steganography methods, the imperceptibility should be considered prior to embedding capacity because we can get the embedding video that the message needed because of the infinite video sequences [2].

There is an exchange-off in the imperceptibility, robustness and embedding capacity. In the video steganography method, if either the robustness or embedding capacity increases, the imperceptibility will reduce.

Recently, numerous video steganography methods have been proposed. The research interests not only focused on the traditional fields (e.g., DST transform domain) but also combined the technologies of the emerging fields, such as artificial intelligence [5-9]. However, there exists a problem that the survey of video steganography lacks sufficient articles. A comprehensive introduction and analysis of the video steganography methods has been provided in this paper. In addition, recommendations and future directions are also suggested to enhance the development of video steganography methods.

The goal of this paper is to make a review on video steganography research, highlight their contributions, and discuss about their challenges. The remainder of this paper is organized as follows. Section 2 introduces the theoretical concepts of the most popular algorithms in video steganography. Section 3 introduces the performance assessment metric for video steganography. And section 4 is the future popular video steganography, including H.265 video steganography, robust video steganography and reversible video steganography. And conclusions are in Section 5.

2. Video Steganography Method

Up to date, with the rapid advancement of Internet and multimedia technologies, the digital videos have become a popular field for data hiding. The infinite video sequences also provide a massive amount of redundancy space for embedding secret message in video steganography.

The existing video steganography algorithms can be divided into three categories according to the embedding position: the pre-embedding (the message embedding position is the raw video domain), the intra-embedding (the message embedding position is the compressed domain) and the post-embedding (the message embedding position is the bitstream domain). The performances of the evaluation criteria of the algorithm should be considered: imperceptibility, robustness, embedding capacity, algorithm complexity, etc.

2.1 Video steganography techniques based on intra-embedding

Intra-embedding combines the embedding process of video coding and syntax elements such as intra-prediction, motion estimation and DCT coefficients: the sender embeds secret message into the process of video, as shown in Fig.3.

The intra-embedding steganography method has greater application and gained more attention because the video is usually transmitted or stored after compression coding. At present, the popular video coding standards H.26X and MPEG-X have high compression ratio, and the video data redundancy has been removed to a great extent after compression coding, which makes it more difficult to embed more data into the compressed video stream [10-12]. In the literatures, most of the intra-embedding steganography method can be selected via part of the video coding structure, including Discrete Cosine/Sine Transform (DCT/DST) [3, 13-27], intra prediction [28-41], motion estimation [42-57, 65], etc., to embed message.

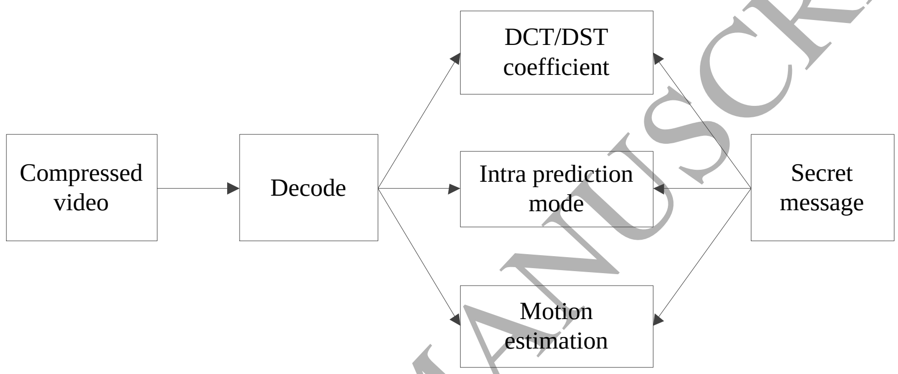

Fig.3 Intra-embedding video steganography

DCT/DST and Quantized DCT/DST (QDCT/QDST) coefficients of the luminance are good candidates to embed secret message because of their low, middle and high frequency coefficients [20]. If the message is embedded into the non-quantized DCT coefficients, the part of the embedded message will be lost after it's been quantified; and if the message is embedded into the quantized DCT coefficients, it can skip the quantization process and can adapt to the lossy compression coding, but it can impact on the visual effect. Video steganography technique based on DCT is one of the most popular methods in H.264 (H.264/AVC), and the existing H.264 video steganography methods based on DCT coefficient usually chooses quantized DCT coefficients to embed message. Fig.4 shows the message is embedded into the quantized DCT coefficients and Fig. 5 shows the message is extracted from the quantized DCT coefficients.

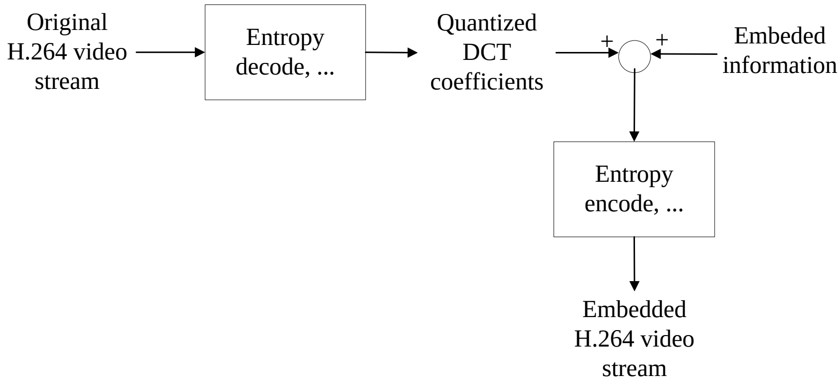

Fig.4 The message embedded into the quantized DCT coefficients

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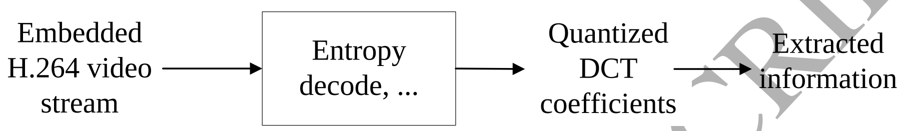

Fig.5 The message extracted from the quantized DCT coefficients

In addition, H.264 has the similar transform manner the coding of the residual samples to H.265 (H.265/HEVC), which means that two-dimensional transforms of DCT can be computed by applying 1-D transforms in the horizontal and vertical directions. In order to reserve the computing precision and orthogonality, the core transform of the DCT coefficients is computed by approximating and scaling DCT basic functions with integer values. The integer transform based on 4×4 block is shown in equation (1), where $Y_{4\times4}$ is the matrix of unscaled DCT coefficients corresponding to the residual block $X_{4\times4}$. In particular, for the transform block size of 4×4 in H.265, the DST integer transform which derived from DCT is applied and shown in (2).The difference between DCT and DST is that DST transform only use to 4×4 blocks in H.265 and DCT can be applied for the other blocks transform in H.264 and H.265 [94].

$$Y = (\mathrm{C}XC^T) \tag{1}$$

Where

$$C = \begin{Bmatrix} 1 & 1 & 1 & 1 \\ 2 & 1 & -1 & -2 \\ 1 & -1 & -1 & 1 \\ 1 & -2 & 2 & -1 \end{Bmatrix}$$

$$Y = (HXH^T) \tag{2}$$

Where

$$H = \begin{Bmatrix} 29 & 55 & 74 & 84 \\ 74 & 74 & 0 & -74 \\ 84 & -29 & -74 & 55 \\ 55 & -84 & 74 & -29 \end{Bmatrix}$$

This section will discuss some H.264 Video steganography techniques based on quantized DCT coefficients. [13] employed a human visual model based on 4×4 block discrete cosine transform to embed the secret message into quantized Alternating Current (AC) DCT coefficients of the luminance residual blocks. The method has not handled the intra-frame distortion drift in H.264. [14] handled the intra-frame distortion drift and proposed an algorithm which embeds secret message into the quantized Direct Current (DC) DCT coefficients of the luminance residual blocks. But the algorithm is detectable and non-blind. [16] developed a group of paired-coefficients which could effectively avoid the intra-frame distortion drift. [3] improved the performance of [16] and proposed an robust without distortion drift steganography algorithm based on BCH, which can correct the error bits caused by network transmission, packet loss, video-processing operations, various attacks, etc. [17] improved [3] and proposed a robust steganography scheme for H.264 by using Shamir's (t, n)-threshold secret sharing and BCH to improve the robustness of the embedded message. [19-22]further provided reversible video steganography methods based on the utilization of BCH code and shamir secret sharing, respectively.

Based on H.265/H.264 intra-prediction coding, the code blocks are encoded by a number of intra-prediction modes. In H.265 codec, the number of intra prediction modes are 35 for each 64×64, 32×32, 16×16, and 8×8 blocks. Fig.6 depicts the 33 angel prediction orientations. And the H.264 codec supports 9 prediction modes for 4×4 blocks and 4 prediction modes for 16×16 blocks. Since the prediction modes play a key role in the compressed procedure, there are a number of methods which utilized the prediction modes to embed message.

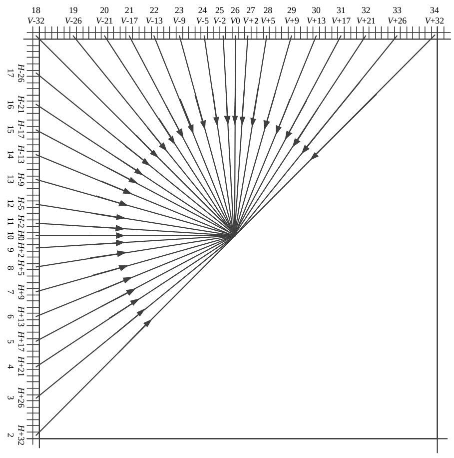

Fig.6 33 angle prediction modes of H.265

Among the steganography algorithms for H.264 based on the intra prediction mode (IPM) [28-37], [28] modified the intra prediction mode based on the mapping between the secret message and the prediction mode. [30] improved the best prediction mode matching method by using the least Lagrangian cost. [31] established a mapping between the message and intra prediction mode with matrix coding. [32] proposed an algorithm based on [31] and utilized an embedding/extracting matrix. Zhang et al. [34] developed a high security adaptive embedding algorithm by using STC (Syndrome-Trellis Code). To resist the detection from [36], [37] introduced the minimizing the “embedding distortion” defined according to SAD (Sum of Absolute Difference).

Motion estimation is used for steganography by modifying motion vector or adjusting the motion vector search process. In the earlier work [42-45], motion vector (MV) was used to hide message usually by directly modifying motion estimation, which is relatively simple, but the embedding performance is not good enough. [47] began to embed secret message by adjusting the parity of the horizontal component and the vertical component. [48] applied matrix coding and phase angle to improve the video quality. [49] inspired by Fridrich et al [50]’s perturbed quantization (PQ) steganography, a technique called perturbed motion estimation (PME) is introduced to minimize the embedding impacts. [52] embedded the message in another way by modifying the search range of motion. [54] designed a MV-distortion function by joining the spatial distortion change (SDC) and the prediction error change (PEC) together, and the two-layered Syndrome Trellis Code (STC). [55] is further utilized to achieve high security level. [56] created N-dimensional motion vector space to get high embedding efficiency. [57] introduced a specific decoded reference frame to overcome the distortion accumulation effects. To resist the steganalysis [51, 58-64] like AoSO and SPOM, [65] further proposed the most suitable CMV (Candidate MV) to guarantee the local optimality of modified motion vectors.

Intra-embedding is easy to allocate the hidden message to the video, and it can get better subjective visual quality and stronger anti-attack ability, but it relies on a specific video codec, and the application scope of the video steganography algorithm is limited to the corresponding codec.

2.2 Video steganography techniques based on pre-embedding

The sender embeds secret message into the non-compressed video stream and then compresses the video, and the receiver decodes the received compressed video and extracts the secret message from the original video. Video steganography based on pre-embedding mainly considers the video sequence as a set of frames, as shown in Fig.7. Pre-embedding video steganography techniques consists of spatial [66-77] and transform domain technique [78-85].

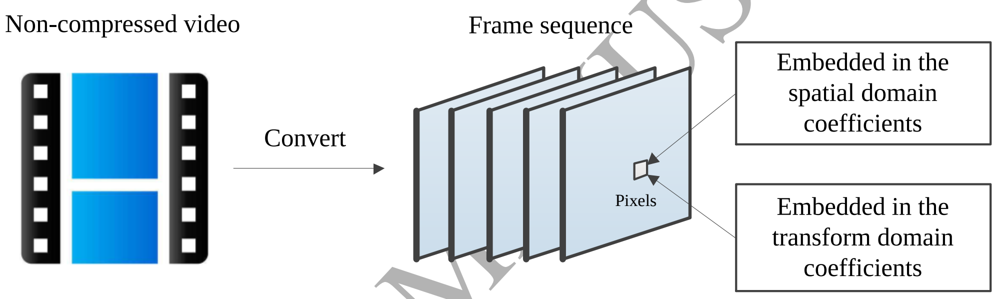

Fig.7 Pre-embedding video steganography

As for the Video steganography techniques based on the spatial domain, [71] embedded secret data in the carrier AVI video file in least significant bit (LSB). The method is simple and has a high embedding capacity, but the robustness is insufficient and hard to resist steganalysis. [72] further proposed a secured hash-based LSB technique (Hash-LSB). In [73], Hash-LSB with the RSA algorithm is implemented to provide a more secure steganography method. [76] developed a blind steganography method based on histogram techniques with an appropriate pixel selection mechanism. [77] introduced a histogram distribution constrained (HDC) scheme to resist H.246 video compression. [74] used region of interest (ROI) to embed the secret message. This method is limited in embedding capacity as only single video frame is considered for embedding stage. [75] combined the Kanade-Lucas-Tomasi (KLT) tracking and Hamming codes (15, 11). The encoded secret message is embedded using an adaptive LSB substitution method in the ROIs of video frames. This method shows good embedding capacity, but the complexity of the operation is also high.

As for the Video steganography techniques based on the transform domain, [79] used face detection and face tracking algorithms to the cover videos in the wavelet domain in order to identify the facial regions of interest. [80] developed a blind adaptive method where human skin regions are regarded as the ROI. The discrete wavelet transform(DWT) coefficients in the skin tone areas guarantee the relatively big amplitude signals which have strong noise immunity. [81] introduced the Hamming and BCH codes to improve the security. The message is embedded into DCT coefficients of each Y, U, and V planes excluding DC coefficients. The visual quality is not very ideal. [82] used DCT and DWT coefficients in combination to enhance the security of hidden message and minimize distortions to maintain better video quality. [83] improved the video steganography method in DWT and DCT domains based on the multiple object tracking (MOT) algorithm and error correcting codes. Motion-based MOT algorithm is implemented on host videos to distinguish the regions of interest in the moving objects. The method showed good security and robustness against various attacks.

The pre-embedding method is independent of the specific video coding process and does not affect the use of the existing standard codec; it can use a variety of message hiding techniques and strategies based on the images [76-77]. However, after video codec the secret message will inevitably have some loss, which is very bad for the extraction and detection of the hidden message [72]. And it takes more time and is not very efficient [84].

2.3 Video steganography techniques based on post-embedding

The post-embedding video steganography algorithm is that the sender directly embeds secret message into compressed bitstream, and the receiver extracts secret messages directly from the received embedded compressed video bit stream. It is not practical to embed the whole bit stream because of the constraints of format compliance and computational complexity. Alternatively, many video steganography algorithms consider the coding structure and embed only a fraction of video data.

H.264 supports two types of entropy (bitstream) coding modules. Context-adaptive variable length coding (CAVLC) [86-88] is supported in H.264 baseline profile and context-adaptive binary arithmetic coding (CABAC) [89-92] is supported in H.264 main profile. CAVLC is a lower complexity but less efficient entropy coder than CABAC [93].The post-embedding process based on H.264/AVC is shown in Fig.8.

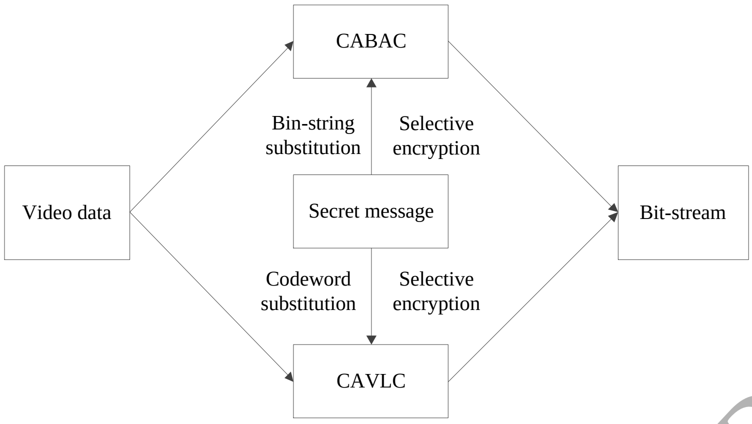

Fig.8 Post-embedding video steganography

Based on CAVLC, the literature [86] proposed a video steganography based on H.264 by Selective Encryption (SE). SE is performed in the CAVLC module of video codec, and CAVLC is converted to an encryption cipher using permutation of equal length codes from a specific variable length coding (VLC) table. [87] used the advanced encryption standard (AES) algorithm to improve SE process. To solve the encrypting problem of nonzero coefficients, [88] proposed a tunable scheme that intra prediction modes and the sign bits of motion vectors were encrypted together.

Based on CABAC, [91] introduced a data-hider to embed the message into partially encrypted H.264/AVC videos by using a CABAC bin-string substitution technique without accessing the plaintext of the video content. Since bin-string substitution is carried out on the residual coefficients, the quality of the decrypted video is satisfactory. [92] improved [91], the encryption of luma prediction modes is designed in addition to residual encryption and motion vector encryption in order to significantly improve the structural deterioration.

The post-embedding method does not need the process of complete decoding and re-encoding, and the computational complexity is low [86]. It will not affect the normal operation of the existing video compression codec, and make the best use of the existing hardware resources [88]. However, because of the operation on video compression bit streams, the video compression codec system is highly dependent. The algorithm design must take into account the factors such as bit stream format, synchronization and transmission conditions [89]. For example, because the limitation of compressed bit rate, the amount of data embedded in video is also limited. Thus the robustness of the format conversion operation is poor [92].

3. Performance Assessment for video steganography

The main goal of video steganography is to conceal the secret message into the digital video, so the visual quality of the embedded video would be changed ranging from a slight distortion to a severe distortion. In order to evaluate the imperceptibility is acceptable or not, several assessment metrics have been used for the evaluation of visual quality, especially for Pick Signal to Noise Ratio (PSNR) and Structural Similarity (SSIM). PSNR is a common assessment metrics which represents the difference between the original and cover videos [16, 25]. In order to be consistent with performance of HVS, SSIM is also used in video steganography [23]. Because PSNR is based on the error between corresponding pixels and the visual characteristics of the human eye are not taken into consideration, the evaluation result is inconsistent with the subjective feeling of the person video quality evaluation based on error sensitivity. And because SSIM is mainly used to measure the structural integrity of frame, the frame is generally divided by a sliding window, where the sliding window is generally a Gaussian window, and the mean, variance and covariance of each window are calculated by Gaussian weighting. Then the calculation of SSIM method is slightly complex, and its value can better reflect the subjective feelings of human eyes. The PSNR and SSIM are defined as follows:

$$PSNR = 10 \times Log_{10}(\frac{MAX_A^2}{MSE})(dB) \tag{3}$$

$$MSE = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}[A(i,j,k)-B(i,j,k)]^2}{a \times b \times c}$$

Where *A* and *B* represent the original and embedded frames, *a* and *b* represent the resolution of the specific videos, *c* refer to the RGB color components. *MAX* represents the highest pixel value in frame A.

$$SSIM = \frac{(2\mu_A\mu_B + C_1)(2\sigma_A + C_2)}{(\mu_A^2 + \mu_B^2 + C_1)(\sigma_A^2 + \sigma_B^2 + C_2)} \tag{4}$$

Where *A* and *B* represent the original and embedded frames, μ_A and σ_A represent the mean and standard deviation values of pixels in frame *A*, C_1 and C_2 refer to a fixed value, respectively.

As mentioned before, the robustness is one important attribute for video steganography method. And the assessment metric indicates that the embedded message whether can be retrieved from the receiver or not. Similarity (*Sim*) and bit error rate (*BER*) have been used to evaluate the robustness performance of video steganography. The Sim and BER can be defined as follows:

$$Sim = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}[M(i,j)\times \hat{M}(i,j)]}{\sqrt{\sum_{i=1}^{a}\sum_{j=1}^{b}M(i,j)^2}\times\sqrt{\sum_{i=1}^{a}\sum_{j=1}^{b}\hat{M}(i,j)^2}} \tag{5}$$

$$BER = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}[M(i,j)\oplus \hat{M}(i,j)]}{a\times b} \tag{6}$$

where $M(i,j)$ and $\hat{M}(i,j)$ are the original and obtained message, $a\times b$ is the size of the embedded message.

The performance of embedding capacity is also a major factor that directly affects the evaluation of the steganography method. The Hiding ratio (*HR*) [83] has been used to evaluate for the embedding capacity in steganography methods and calculated in the following formula:

$$HR = \frac{Size\ of\ \ the\ embedded\ \ message}{Video\ size}\times 100\% \tag{7}$$

Table I provides the performance of intra-embedding, pre-embedding and post-embedding methods in terms of visual quality, robustness and embedding capacity. It can be seen from Table I that the intra-embedding methods have a high visual quality, but the embedding capacity is small. In addition, the performance of robustness in these methods are not always considered, which was easily detected by various steganography methods. Embedding capacity and robustness are properties that need to be further enhanced in the future. The pre-embedding methods based on spatial/transform domain generally have relatively good embedding capacity and visual quality, but the main challenge is its robustness to resist the vulnerability of any unexpected modification including compression, format change, etc. Therefore, such methods must improve the robustness against compression, signal processing, noises, etc. The post-embedding methods modify entropy elements based on CAVLC or CABAC and achieve the robustness performance. However, the visual quality of the post-embedding methods is not very good when compared to the intra-embedding methods. It can be seen that there still exist improvement in terms of visual quality, embedding capacity and robustness.

Table I: Embedding capacity, video quality and robustness comparison of the video steganography method classifications

Method	Intra-/pre-/post-embedding	HR	PSNR	robustness
Algorithm in[[16]	Intra-embedding	0.10%	40.74dB	×
Algorithm in[[20]	Intra-embedding	0.09%	46.35dB	√
Algorithm in [27]	Intra-embedding	1.04%	37.00dB	×
Algorithm in[40]	Intra-embedding	1.62%	40.25 dB	×
Algorithm in[56]	Intra-embedding	0.03%	36.79 dB	×
Algorithm in [73]	pre-embedding	1.03%	59.63dB	×
Algorithm in [72]	pre-embedding	1.34%	36.97dB	√
Algorithm in [76]	pre-embedding	1.50%	29.03dB	×
Algorithm in [89]	post-embedding	2.44%	34.54dB	√
Algorithm in [90]	post-embedding	0.57%	37.05dB	√

4. Future popular video steganography

In this section, we introduce the future popular video steganography, including H.265 video steganography, robust video steganography and reversible video steganography.

4.1 H.265 Video steganography

H.265 is the latest video coding standard published by ITU-T/VCEG and ISO/IEC MPEG [94]. H.265's main achievement is its significant improvement in compression performance when compared to the previous state-of-the-art standard with at least 50% reduction in bitrate for producing video of similar perceptual quality [95], which is well adapted for high definition video applications and will become more popular video technologies. The significance of video steganography based on H.265 can be highlighted as follows: 1) with the growing popularity of HD (high definition) and the emergence of beyond-HD formats such as 8k×4k resolution, video steganography based on H.265 can effectively satisfy the needs for protection of the secret information related to the HD video content. 2) With the higher compression performance compared to H.264, the video steganography methods based on H.265 can obtain higher safe mechanism to conceal the secret message, better tradeoff between visual quality, embedding capacity and robustness, and make it more appropriate for HD network transmission.

The existing H.265 video data hiding schemes are studied by few scholars since H.265 is recently finalized. [24] employed the three-coefficients to solve the DST coefficient distortion drift problem for 4×4 luminance blocks in H.265. [25] furthered a group of decision conditions to increase the visual quality of embedded video, but the embedding capacity is reduced. [26] introduced a multivariate array to realize reversible steganography in 4×4 luminance DST blocks. However, each 4×4 luminance block can only be embedded in 1 bit of message, so the embedding capacity is limited. To solve the DCT coefficient distortion drift problem in H.265. [27] proposed a group of paired-coefficients for 8×8 luminance DCT blocks which had a similar effect to the paired-coefficients used in [16], but the visual quality is not ideal enough. [38] used the mapping between (4,3) code standard array decoding table and the intra prediction mode to reduce the impact of the prediction mode modulation, but the algorithm has a high complexity. [39] further utilized Local Binary Patterns (LBP) to scan high complexity texture as the embedding area. [40] developed the mapping relationship between the angle differences and secret message, which the embedding capacity is insufficient because the modulation range is too large. [41] optimized the mapping relationship with a Lagrange rate distortion model. Although the embedding capacity is slightly larger than [28], it is still limited. [56] created N-dimensional motion vector space with a mapping relationship and realized that a 2N+1-ary number can be embedded by modifying at most one element in a set of N motion vector components, which has high embedding efficiency. [96] proposed for H.265 video by using the coding block size feature in H.265 , the nonzero DCT coefficients are manipulated based on the transform block size in all slices and a data hiding technique is proposed to adaptively manipulate the prediction block size. These techniques have the potential to be further fine-tuned to handle. [97] modified the LSB of the selected QTCs and embedded one of the watermark bit (Mb) in each QTC. Consequently, further studies and investigations are required.

4.2 Robust video steganography

The robust video steganography (as shown in Fig.9) will become more popular because the security problem in information field is becoming more and more serious and the video has infinite sequences. And BCH [98-104], secret sharing [105-119] and Forbidden Zone [120-125] have been applied successfully to improve the robustness.

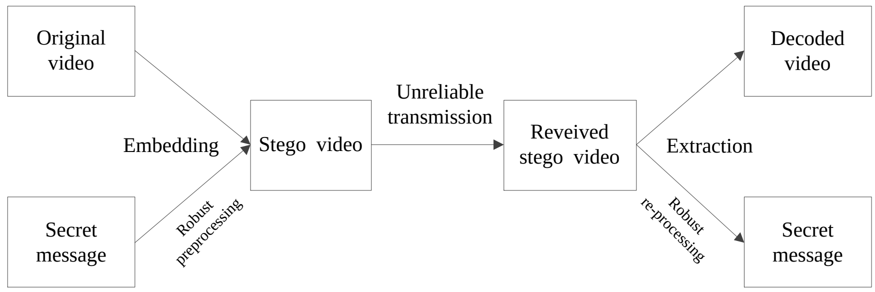

Fig.9 Robust video steganography

Bose, Chaudhuri, and Hocquenghem invented the BCH encoder. It is one of the most powerful random cyclic code methods, which can be used for detecting and correcting error bit. Binary BCH (n, k, t) codes can correct up to t errors, where n is the code-word length and k is the code dimension. The core generalized parity-check matrix *B* for BCH(*n*, *k*, *t*) can be represented as follows:

$$\mathrm{B}=\begin{bmatrix} 1 & \alpha & \alpha^2 & \cdots & \alpha^{n-1} \\ 1 & \alpha^3 & \left(\alpha^3\right)^2 & \cdots & \left(\alpha^3\right)^{n-1} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ 1 & \alpha^{2t-1} & \left(\alpha^{2t-1}\right)^2 & \cdots & \left(\alpha^{2t-1}\right)^{n-1} \end{bmatrix} \tag{7}$$

Where α is the primitive element in Galois field $GF(2^m)$, *m* is the order of the Galois field $GF(2^m)$.

Let the single-bit error rate be *p*, then the error rate after BCH(*n*, *k*, *t*) encoding is as follows:

$$p_{BCH} \leq \sum_{i=t+1}^{n} \frac{i+t}{n} C_n^i p^i \ (1-p)^{n-i} \tag{8}$$

[99] proposed an efficient steganography method using BCH code. The embedding process is completed by changing various coefficients in order to make the syndrome values null. The method improves both capacity and computational time compared with other algorithms, which improves the system complexity from exponential to linear. In 2013, Liu et al. proposed a robust steganography scheme based on H.264 without intra-frame distortion drift. This process depends on the prediction of the intra-frame modes of neighboring blocks to avert the intra-frame distortion drift. To improve system efficiency and robustness, Liu et al. used BCH code before embedding message. Then, the encoded message is embedded into the 4x4 DCT block of quantized coefficients with a luminance component of the intra-frame [100]. In 2014, [101] proposed an adaptive steganography algorithm using a linear error correcting code and demonstrated that code is a better encoding algorithm than all other codes. In 2016, [103] improved [102] which proposed DCT-based robust video steganography

method using BCH error correcting codes, which converts the video into frames and divides each frame into Y, U, and V components. Prior to the embedding process, the secret message is encrypted and encoded by using BCH codes. And in 2015, a high payload video steganography algorithm in DWT domain is based on BCH codes.

The Shamir's (k, n)-threshold secret sharing (secret sharing) scheme provides an elegant construction of a perfect (t, n)-threshold scheme using a classical algorithm called Lagrange interpolation. Recently, the secret sharing has been used with video cryptography methods. In here, k $\leqslant$ n and the secret message is obtained when k secret shares are combined [105]. Some images and document data hiding techniques, etc based on secret sharing have been implemented in the literature [106-118]. [17] proposed a robust video steganography method using secret sharing resistance to the error frame. And [19-20] used secret sharing to improve the robustness of a reversible H.264 steganography. [119] presented a hierarchical frame work for video authentication based on cryptographic secret sharing that protects a video from spatial cropping and temporal jittering, yet is robust and resists frame dropping in the streaming video scenario.

Forbidden zone (FZ) is defined as the host signal range, where no alteration is allowed. Forbidden Zone Data Hiding (FZDH) makes use of FZ to adjust the robustness-invisibility trade-off. The embedder and decoder functions of FZDH are given in the paper [120]. Recently, Forbidden zone is used in video steganography[121-125]. [121] proposed a new video data hiding framework that makes use of erasure correction capability of repeat accumulate codes and superiority of FZDH. The proposed framework is tested by typical broadcast material against MPEG-2, H.264 compression, frame-rate conversion and frame manipulation attacks via frame synchronization markers. [123] implemented an advanced video data hiding method that performs erasure correction capability of repeat accumulate codes and superiority of forbidden zone data hiding. This method includes a temporal synchronization scheme in the sequence to resist insert attacks and frame drop. [125] made use of correction ability of duplication store codes and advantage of forbidden zone data hiding was used.

4.3 Reversible Video Steganography

In most cases, the video will be affected by some distortion after steganography and the processed video cannot be recovered completely. And, in some applications, such as medical diagnosis, military video, remote sensing video processing, legal certification and evidence, etc, they are critical to restore the original video [126]. Reversible steganography is a technique by which the original video can be recovered exactly, and it can be used in a variety of domains at present, as shown in Fig.10. Some reversible steganography techniques have been reported in some literatures, and most of the them are based on difference-expansion [128-134], histogram shifting [135-139], DCT coefficients [17-20,140-142,] and DWT, VQ, motion vector and so on [143-149], etc., to embed message.

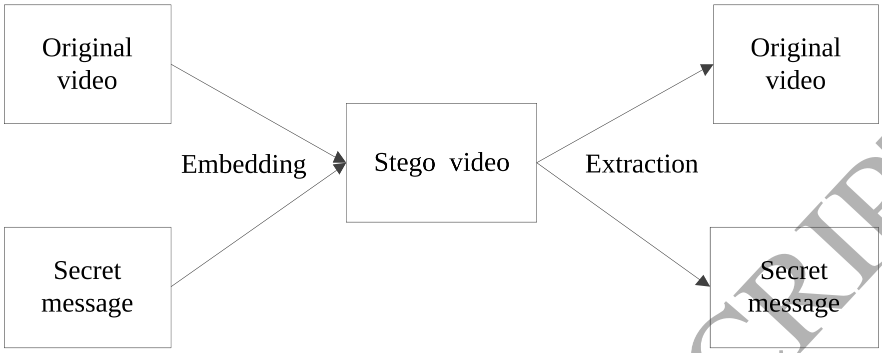

Fig.10 Reversible video steganography

The first reversible data hiding algorithm was the patent submitted by Bart [127]. After that, the reversible steganography algorithms were constantly emerging. In 2003, [133] proposed a difference-expansion image method without compressing the original medium，which achieved reversibility by the correlation of adjacent pixels. It was researched by many other researchers and had a profound impact on reversible steganography technology development [129-134]. [135] presented another representative reversible data hiding algorithm based on the histogram shifting, which utilized the zero or the minimum points of the histogram of an image and slightly modified the pixel brightness levels to embed message into the image. Afterwards, it has been improved by many researchers [136-139]. Currently, most of the existing reversible video steganography algorithms mainly embed the data into the DCT coefficients of I-frames [17-20, 26, 140-143,]. In [140], the authors presented a new reversible data hiding algorithm based on integer transform and adaptive embedding. [141-143] discussed a variety of robust data hiding algorithms in detail. There are many other methods that use other coefficients such as DWT, VQ, motion vector and so on [143-145]. In [145], the authors researched a novel high capacity reversible image data hiding scheme using a prediction technique which was effective for error resilience in H.264/AVC. Many other methods were presented in [146-151]. In previous work, most of the algorithms inevitably encountered distortion drift problem including intra and inter. And all the mentioned algorithms were only for 2D fields. [143] presented a reversible video steganography scheme for hiding secret message into the motion vector of each block in 3D MVC videos. [26] introduced a multivariate array to realize reversible steganography in 4×4 luminance DST blocks based on H.265.

4.4 Video steganography based on Artificial Intelligence

Video steganography is a multidisciplinary research area involving theory of communications, signal processing, multimedia coding, message theory, cryptography, etc. Artificial Intelligence (AI) including machine learning [152-155,174-182], pattern recognition [157-160,178-180], heuristic optimization [162-168] is one sub branch of computer science, which can be used to steganography technology and can achieve high visual quality, robustness, low cost, optimal and adaptive solutions. Recently, AI technology is rarely used in video steganography , though applied to various kinds of image steganography，including Particle Swarm Optimization [156, 161], Ant Colony Optimization [169-176], Neural Networks Support Vector Machine [177], Genetic Algorithms [181-190],and etc. In [186], the scheme based LSB has been used as a base technique for video steganography and GA has been used as an optimizer to modify embedded pixels coefficients, so that some target performance will be optimized. Fig. 11 shows how to use GA as an optimizer in [186]. Due to the generality of image steganography and pre-embedding video steganography, the AI technology applied to image steganography has great reference value for pre-embedding video steganography.

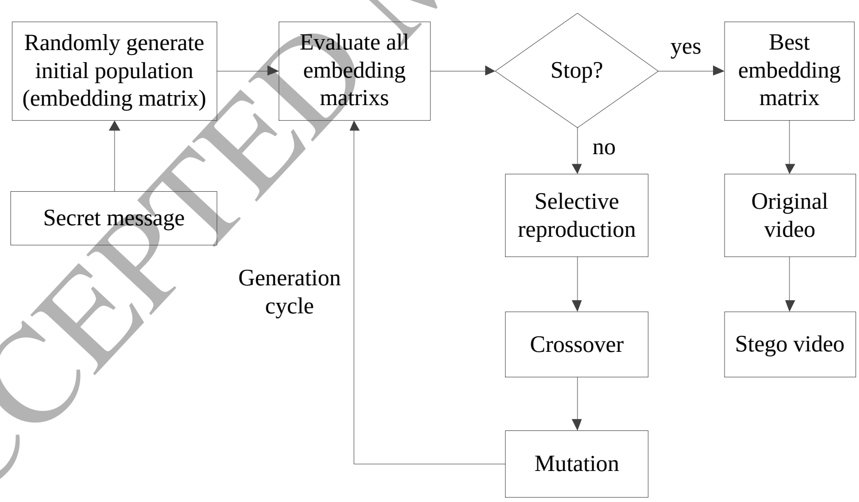

Fig.11 GA as an optimizer in [186]

5. Conclusion and challenges

In this paper, we have presented a systematic overview of the video steganography method, and the video steganography is divided into intra-embedding, pre-embedding and post-embedding according to the embedded position of secret information. The performance of video steganography and the future popular video steganography including H.265, robust, and reversible video steganography are also discussed. And the challenges on video steganography are shown as follows:

1) The video steganography method which can obtain a good trade-off between the performance of visual quality, high embedding capacity and strong robustness to resist a number of unexpected attacks is the first challenge.

2) The video steganography method which can be combined with other techniques such as artificial intelligence is the second challenge. Video steganography with artificial intelligence will enhance the visual quality and the secret protection of video steganography, which could use a portion of the video to embed data, for instance, embedding message could be embedded into the region of interest human behaviors, moving cars and so on.

3) The third challenge in video steganography is how to effectively combine the steganography with other protection technologies such as cryptography and error correcting codes, which can improve the security of the secret message and make the video steganography to be suitable for various unsafe application scenes.

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