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A Comprehensive Examination of Digital Video Watermarking Schemes Based on Wavelets

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Abstract: **Recent improvements in technology enable digital content to be amended and accessed without significant specialist delivery and without restrictions. Without emerging safety techniques, it is highly challenging to rely on digital storage and communication systems for commercial, military, and medical uses. The watermarking process is one technique that assists in safeguarding digital assets from unauthorized access. In the present article, many watermarking systems for videos are addressed, which are based on transformation techniques including principal component analysis (PCA), discrete wavelet transformation (DWT), discrete cosine technique (DCT), and discrete Fourier transform (DFT).**

Keywords: discrete Fourier transform, discrete cosine technique, principal component analysis, discrete wavelet transformation.

I. INTRODUCTION

The digital video is composed of frames, which are subsequent still images. The proliferation of media sharing brought about by the development of Internet services and various storage technologies has made the protection of digital video an increasingly pressing issue. These issues spurred the team to create an algorithm that would halt such attacks by adding protection to the digital footage. Digital watermarking is the process of employing certain algorithms to incorporate a secret message or logo into the host media source. It offers a high degree of protection against unwanted access and verifies the integrity or authenticity of the digital video. Watermarking videos is usually done for security reasons. Watermarking is commonly employed in an assortment of contexts, including copy protection [8], fingerprinting, ownership identification, authentication, monitoring digital video broadcasts [8], video authentication, software that renders on-screen casting tools unusable, source tracing, etc.

There are two types of attacks related to digital video watermarking. The first type of attack is intentional, and it encompasses single-frame attacks including filtering, contrast and color enhancement, and noise accumulation. Averaging attacks and collision attacks are examples of statistical assaults. Another factor that could lead to unintentional attacks is degradation that can occur from lossy copying, compression of the video during re-encoding, or variations in frame bit rate and resolution. Attacks by hackers using techniques like compression [1], frame switching, frame averaging, etc. are commonplace for watermarked films. The watermarking system has several characteristics, such as robustness, capacity, fidelity of the data payload, and efficacy of embedding. The number of bits of data that can be retained in a watermark is known as the payload.

The total amount of data required for integrating a single unit of watermark information is known as the watermark granularity. Perceptual transparency is the extent to which watermarked content containing embedded watermarks is invisible to the viewer. The watermarking process necessitates certain things, one of which is perceived transparency. Robustness and temper resistance are two additional needs that contradict one another. The resistance provided by the embedded watermark against removal by standard signal processing operations is known as robustness. Images, video, and audio are subjected to various digital signal processing techniques, including filtering, compression, rotation, and others, during the processing phase. A watermark needs to be introduced to a perceptually significant portion of the media for the purpose of achieving resilience. The quantity of information that can be generated by inserting a watermark is referred to as the capacity. An algorithm for watermark embedding needs to be able to hold an increasing amount of data. Watermarking algorithm integrity is guaranteed in a manner akin to that of encryption techniques. As per Kerckhoff's assumption, the watermark embedding procedure can be considered public, whereas the protection is contingent solely on the selection of a key from an expansive key space.

The preliminary wavelet originated from the Haar base function, which Haar discovered around 1910. In the early 1980s, Morlet and Grossman created a significant stir in the wavelet community when they presented the continuous wavelet transform. Daubechies effectively constructed an orthogonal wavelet with minimal accompaniment after it. Mallat integrated it into a multi-resolution representation to present a reliable system for signal analysis. A technique termed a wavelet transform can be used to "cut up" data by representing it as multiple frequency components using functions or operators. It is employed to investigate every constituent at a resolution commensurate with its magnitude [14].

Wavelet has a wide range of potential uses, including electromagnetic wave scattering, image processing, pattern recognition, medical diagnostics, geophysical signal processing,

and boundary value concerns. Seismic tremors, human voice,

engine vibrations, medical imaging, financial data, music, video, and many other kinds of signals can all be analyzed using the wavelet technique.

II. RELATED WORK

The watermarking methodologies can be done in various ways as shown in Fig.1

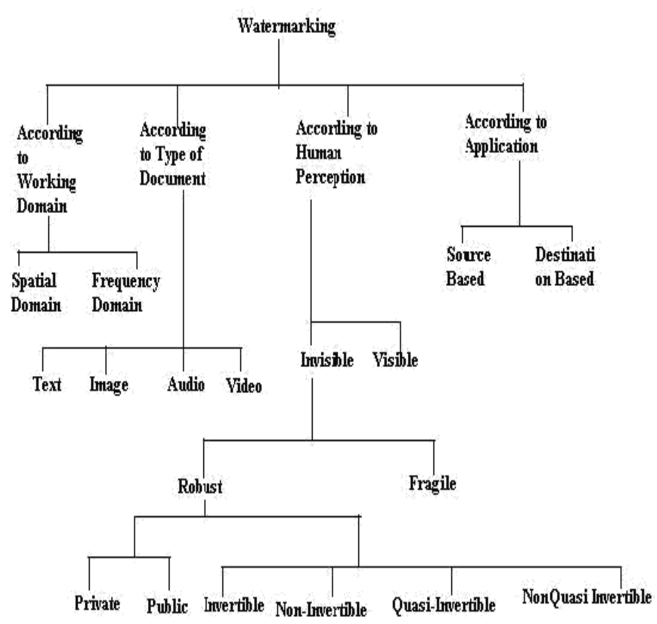

Fig.1: Classification of watermarking Methodologies

A. Spatial Domain Techniques of watermarking

In the spatial domain, watermarking is a deliberate, low- complexity procedure that is typically applied to the color and luminance elements. Because the dimensions of pixels have been modified, it is often referred to as a raster domain technique. The watermark is directly included in the host video's individual pixel value. A predetermined rule changes the value of a pixel in the host video according to the watermark bit. While spatial domain techniques are simple and low- complexity, they are not as robust or secure. Various techniques for watermarking exist in the spatial domain, including

1. Least Significant Bit Technique

It is straightforward and simple to comprehend, encouraging the watermark with the least essential components. The information or watermark bit is inserted into the least significant bit of each pixel. Considering the least essential piece of each pixel has the least weight, altering this bit has relatively little impact on the image's quality. Its low security is an inconvenience, despite its great capacity. In addition to its lack of stability, LLB is not recommended for use in watermarking applications, but it makes sense for steganography applications.

2. Correlation Based Watermarking Technique

The brightness value of each pixel in the host file (image or video) in the spatial domain is increased by the pseudo-random number sequence, which is an array of numbers that is randomly created. If the watermark is represented by W(i,j) and the luminance value of the pixel is represented by I(i,j), the watermarked image can be supplied by

$$I(i,j) + k \times W(i,j) = Iw(i,j)$$

Here, Iw is the watermarked host, and k is a gain factor. The robustness and outstanding quality of the host image are provided by the spatial domain. The host's quality decreases by a higher value of k, but the image's robustness is also increased. Although a lower value of k has somewhat of an impact on host quality, it also lessens robustness.

In the extraction step of the spatial domain, the watermark is extracted from the host using the key that initializes the pseudo- random number sequence. The watermark bit is identified and retrieved during the extraction phase if the correlation between the noisy watermarked host and pseudo-random sequence is found to be greater than a predetermined threshold (T).

B. Frequency Domain Watermarking Techniques.

When employing many transform techniques, such as the Discrete Fourier transform (DFT), Discrete Cosine Transform (DCT), Principal Component Analysis (PCA), and Discrete Wavelet Transform, the frequency domain embedding of a watermark is more reliable than the spatial domain embedding (DWT).The host file is converted to frequency domain using these methods. The transform domain technique is another name for the frequency domain approach. The problem or restriction presented by the spatial domain approaches can be solved by the transform domain techniques; however they need more processing power.

1. Discrete Fourier Transform

The video is broken down into frames, and the DFT coefficients are calculated for each frame. Every frame's DFT coefficients are adjusted based on the watermark bit. After the watermark has been included into the frames, the watermarked video is obtained by computing the opposite discrete transform, which first recovers the watermarked frames before converting them into a video. When it comes to image processing operations like filtering, compression, rotation, and cropping, the DFT offers good robustness.

2. Discrete Cosine Transform

DCT may be utilized for O (n log n) operations and is faster. It is significantly simpler to add watermarking information to an image's middle frequency bands when it is divided up into many frequency bands using the DCT. The middle frequency bands are chosen such that they avoid the areas of the image that are most visually significant (low frequencies), without putting themselves too much at risk from noise and compression attacks (high frequencies).

A signal or image is converted from the spatial domain to the frequency domain using the DCT. The most resilient watermarking method to lossy compression is DCT-based. The DCT offers high-quality cooperation between computational complexity and information stuffing capacity.

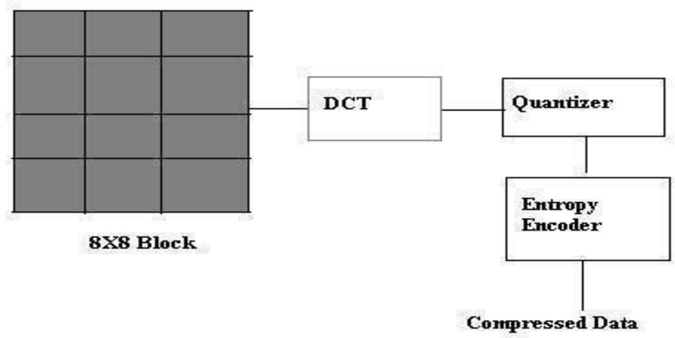

Fig.2: Discrete Cosine Transform

3. ***Principal Component Analysis (PCA)***

The principle Component Analysis (PCA) is a mathematical procedure that depicts a collection of correlated variable annotations on a principle component set of values that are uncorrelated. It does this by applying an orthogonal transformation. The data with the highest covariance are shown together in a new coordinate system created by PCA. The data set's dimensionality is decreased using the main component psychoanalysis. The watermark is embedded into a donation video file using the RGB three color channels. The video frames are partitioned down into various frequency sub-bands. Using contourlet transform, the watermark is also broken in a different frequency range. The low frequency band of the host video then contains this watermark band encoded in it. In order to retrieve the original host video, the inverse Contourlet transform is finally applied.

4. ***Discrete Wavelet Transform***

The DWT is a way of employing 2-D filters to the image in each which point the next coarser scale of wavelet coefficients is obtained. The watermarking system that is DWT based is the most resilient to noise addition.

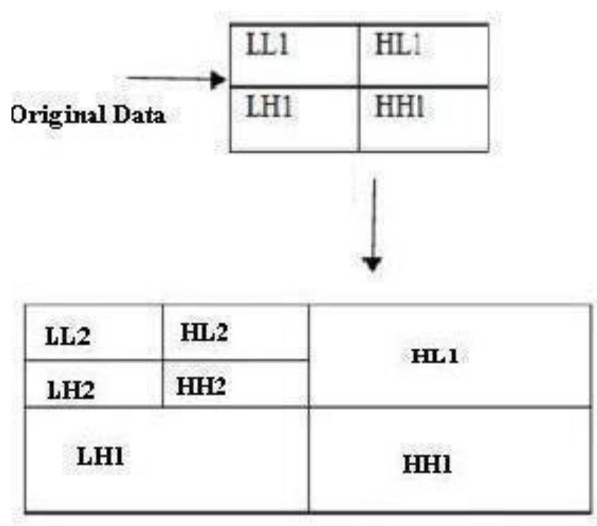

Fig. 3: Discrete Wavelet Transform

Wavelet Tee is an innovative kind of data structure designed to improve the toughness of significance maps of wavelet coefficients. It is possible to create a parent-child link between wavelet coefficients at several scales that are comparable to the same place. Every coefficient at a particular scale can be connected to a set of coefficients at the next finer scale of comparable orientation, with the exception of the highest frequency sub-bands (HL1, LH1, and HH1). All coefficients corresponding to the same spatial position at the next finer scale of identical orientation are referred to as children, while the coefficient at the coarse level is referred to as the parent. The collection of all coefficients at all finer scales with analogous orientation that correspond to the same places for a given parent is referred to as its offspring. Ancestor refers to the set of coefficients for a particular kid that are present at all coarser scales of an analogous direction that relate to the same location. For instance, in the four level wavelet decomposition, the projectile points from the parents' sub-band to the kids' sub-band. Top left represents the lowest frequency sub-band, while bottom right represents the highest frequency sub-band. The collection of coefficient methods that are based on the EZTW (Embedded Zero Tree Wavelet)[19].

An overview of the paper's fundamental embedding algorithm is as follows: dimension. The input image is split into four non-overlapping

1. *Watermark pre-process:* - As part of preliminary processing, a multi-resolution sub-bands (LL, LH, HL, and HH) by the filters. The coarse-scale DWT coefficients are represented by the LL sub-band, and the fine-scale DWT coefficients are represented by the LH, HL, and HH sub-bands. The LL sub-band is processed one more time until some final scale N is reached, at watermark is divided into smaller portions. First, the watermark is scaled to a specific size as

$2 ^ n <= m; n > 0$

$p + q = n; p, q > 0$

Where m – No. of Scene Changes p, q, n – No. of Positive Integer.

The Size of watermark is determined by,

$64.2 ^ p *64.2 ^ q$

Next, the watermark has been divided into two tiny, 64-size pictures. Eight bit-planes are created from each little image, and a huge image can be created by aligning the bit-planes side by side so that they only contain 0s and 1s. Watermarks are made from these processed photos.

2. *Video pre-process:* - Through the use of a separable two- dimensional wavelet transform, every frame in the movie is broken down into 4-level sub band frames. Using the histogram difference approach on the video stream, scene changes are identified in the video.

3. *Watermark embedding:* - By adjusting a few DWT coefficients' positions, the watermark is added to the video frames under the following restrictions:

If Wj= 1 then

Exchange (Ci, Ci+1, Ci+2, Ci+3, Ci+4); else
Exchange (Ci, Ci+1, Ci+2, Ci+3, Ci+4);

end if

Where Ci is the ith DWT coefficient of a video frame Wj is the jth pixel of a corresponding watermark image.

4. *Watermark detection:* To identify the video watermark, the video is analyzed. The following logic is used to perform the detection.

If (WC (i) > median (WCi, WCi+!, WCi+2, WCi+3,WCi+4);
Then EWj Else EWj = 0 end if

Every signal S can be represented using wavelet base functions as follows.

$$S(t) = \sum_{m \in R} \sum_{n \in Z} d_n^m \psi_{m,n}^{(\lambda_o, t_o)}(t)$$

where

$$d_n^m(t) = \left(S(t), \psi_{m,n}^{(\lambda_o, t_o)}\right) = \sum_n S(t) \psi_{m,n}^{(\lambda_o, t_o)}(t)$$

Where R and Z represent the set of all integers and real numbers.

$$\psi_{m,n}^{(\lambda_o, t_o)}(t) = \lambda_o^{-m/2} \psi(\lambda_o^{-m} t - n t_o)$$

d^m is the detail coefficient φm, n is the wavelets function generated from the original mother wavelets $\psi \in L^2(R)$, λ_o is the scale space parameter, to is the translation space param- eter, m is the scale or level of decomposition, and n is the shift- ing or translation integer.

A wavelet's frame is formed by the scale and translation parameters, and its spectrum serves as a comprehensive representation of the signal. For small scales, the depiction is on a narrow grid, while for big scales, it is on a wide grid.

The discrete wavelet transform (DWT) coefficients $\omega_{i,j}$of a signal or a function f(x) are computed by the following inner product

$$\omega_{j,k} = (f(x), \psi_{j,k}(x))$$

Where $\omega_{j,k}$is the wavelet expansion function and both j and k are integer indices for the scale and translation of the wavelet function, respectively. The inverse wavelet transform is used for the reconstruction of the signal from the wavelet coeffi-cients $\omega_{j,k}$.

$$f(x) = \sum_j \sum_k \omega_{j,k}, \psi_{j,k}(x)$$

There are several wavelet analysis, synthesis, and related processing algorithms as follows.

1. Speeded Up Robust Feature

In order to satisfy the requirements of invisibility and resilience against malicious assaults, the typical featured blocks for embedding are identified using the SURF approach [5]. By using an error-correction code to shield the watermark from bit mistakes, it offers increased robustness. To increase the watermark correlation, the watermark is placed for each group of frames in an input video. The resilience to popular image processing threats, as JPEG2000 compression, frame averaging, and frame swapping attacks. A watermarked video has a great quality and is imperceptible because to the inserted watermark.

To create watermarked video of the highest caliber that can withstand compression, PSNR readings over 45 dB, and common image processing attacks. to get a high-caliber overall performance that is resistant to compression attacks. The following is the watermark embedding algorithm:

Step 1: A total of Fm and Fp frames are randomly selected from a test video. Using symmetric key k2, the selected frames are denoted by Fp. Each frame is broken into blocks of size b × b, and the chosen frames must be large enough to incorporate a watermark image of size m × n.

Step 2: The frame is split up into b × b blocks. The blocks that have the greatest and most significant points of interest are selected. After error correction, the number of blocks selected should match the updated dimensions of the watermark logo, which is m × n.

Step 3: From an extracted RGB block, the luminance component Y is obtained in frame Fp and is represented as L(ip jp).

Step 4: The chosen luminance component of the block is subjected to the second level of DMWT decomposition. DCT is used to transform the LL sub-band that was obtained.

Step 5: The symmetric key k3 selects a set of c DCT coefficients, or xi. These coefficients have a quantization based on the watermark image bits.

Step 6. An evolutionary method is used to optimize the quantization step size q.

$$\begin{gathered} \text{if}(w==1) \\ k_3 = 0.75 \\ \text{else} \quad k_3 = 0.25 \\ \text{if} \ x(i) > 0 \\ x'(i) = x(i) - x(i) \bmod (q) + k_3 \times q \\ \text{else} \\ x'(i) = x(i) - \text{sign}(x(i)) \times \text{abs}(x(i) \bmod q) - k_3 \times \end{gathered}$$

Where x (i) and x „(i) are DCT coefficients.

Step 7: On the chosen block, an inverse DCT is performed.

Step 8: To create the watermarked block, an inverse DMWT with additional sub-bands is run. RGB bricks are created from these chosen blocks.

Step 9: To obtain the watermarked frames, repeat Steps 3 through 7 for the remaining selected blocks.

Step 10: The average PSNR, or PSNRavg, is computed using the following formula across Fm frames:

$$\text{PSNR}_{\text{avg}} = \frac{\sum_{j=1}^{F_m} \text{PSNR}(j)}{F_m}.$$

2. Complete Qualified Significant Wavelet Tree Quantization

A compact multiresolution representation of important maps is offered by the CQSWT [3]. The positions of the significant coefficients are represented by these binary maps, which are considered significant. The CQSWT makes it possible to effectively express the successful cross-scale prediction of negligible coefficients as a component of exponentially increasing trees. It also employs a prioritizing strategy in which the wavelet coefficients' spatial position, precision, magnitude, and scale dictate the order in which the wavelet coefficients are prioritized.

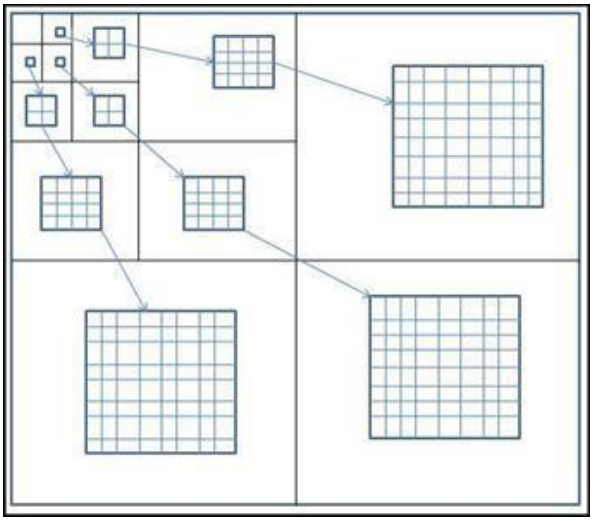

Fig. 4: Tree Structure of Wavelet Coefficients

From the coarsest scale to the finest scale, all of the wavelet coefficients xn(i,j) ´ D satisfy |xn(i,j) > |x1(i,j) > Tn|, |xn-1(i,j) > T2|, |xn-3(i,j) > T3|, etc. given a set of thresholds T1, T2,... Tn is referred to as the Complete Qualified Significant Wavelet Tree (CQSWT), as are xn(i,j) and all of its offspring. Using the L level decomposition of DWT, the host image of size NxN is converted into wavelet coefficients, allowing for the possibility of having L×3+1 frequency bands. Figure 4 displays four levels for L = 4. The LL4 subband, which is the lowest frequency subband, is at the top left, and the HH1 subband, which is the highest frequency subband, is at the bottom right. The connection between these visualize the frequency bands from the blocks of varied size as a parent-child connection. A wavelet tree can be formed by associating these sub nodes in a parent-child connection, with the exception of the lowest frequency subband LL4.

Higher level subbands, like the HL4 subband, are more significant than lower level subbands, like the HL2 subband, when it comes to CQSWT. With the exception of the LL band coefficients (A4,4), the coefficients are grouped based on wavelet trees. Consequently, the wavelet tree's roots are formed by the coefficients in subbands A4,1, A4,2, and A4, 3. Using a 512x512 four-level wavelet transform image, the subbands A4,1, A4,2, and A4,3 have 322 coefficients at the fourth level, and the total number of trees in CQSWT is 3×322 = 3072. As seen in fig. 4, each tree has 1+4 + 16+64 = 85 coefficients. The order of the coefficients is parent to kid.

There are (N/4)2 coefficients and a total of 3×(N/4)2 trees for an image of size N×N at level two. With a very good PSNR value of 38.2 dB and correlation coefficient values above 0.7 for every image, the CQSWT performs exceptionally well. It has excellent resilience against a wide range of harmful modifications, such as cropping, rescaling, low-pass filtering, median filtering, and JPEG and JPEG2000 compression.

3. Qualified Significant Even Wavelet Tree

The robustness of the watermarking system is achieved by the QSEWT by employing wavelets based on EZW and Haar wavelets. Using the L level DWT, the host picture of size n by n is converted into wavelet coefficients. L×3+1 frequency bands are possible with L level decomposition. It is possible to think of the relationship between these frequency bands from the blocks of varied size as a parent-child relationship. A wavelet tree can be formed by connecting the parent-child association between these sub nodes, except for the lowest frequency sub band LL4.

An image will contain many wavelet trees if the root is made up of multiple nodes, as will be discussed below. With the exception of the lowest frequency sub band, a wavelet tree descending from a coefficient in QSEWT sub band HH4 shows that all parents have four children. The parent-child connection is defined for the lowest frequency sub band so that every parent node has three offspring in the QSEWT. The way the coefficients are scanned makes sure that no child node is scanned ahead of its parent. The scanning process for a

N scale transform starts at the lowest frequency sub band, designated as LLN, and proceeds to scan the subbands HLN, LHN, and HHN before proceeding to the scale N-1, and so on. Prior to every coefficient in the following finer sub band, every coefficient in the current coarser sub band is scanned.

With a very good PSNR value of 39.1 dB, the CQSWT exhibits correlation coefficient values over 0.7 and an NCC derived watermark value of up to 0.9 across all pictures. It has excellent resilience against a range of malevolent manipulations, such as median filtering and low-pass. JPEG and JPEG2000 compression, image rescaling, cropping, and filtering.

CONCLUSION

The current study examined a number of video watermarking strategies and found the following information about several video watermarking approaches. The study's findings show that the assessed strategies can withstand a variety of attacks, provide a higher PSNR, and maintain good quality in terms of the embedding procedure's efficiency, security, and resilience without significantly lowering the quality of the video.

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