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A Resilient Video Wavering Approach Using Dualistic-Tree Complicated Wavelength Transmute and Solo Virtue Disintegration for Enhanced Security and Resilience

Shoyeb Karim Pathan[1]*, Meesala Sudhir Kumar[2]
[1]*School of computer science and engineering, Sandip University, Nashik*
Shoeb.pathan007@gmail.com
[2]*School of computer science and engineering, Sandip University, Nashik*
sudhir.meesala@sandipuniversity.edu.in

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ABSTRACT

Wavering can be used in digital multimedia for securing content to prevent misuse and ensure its authenticity. In this paper, we are presenting a novel video wavering scheme which integrates Dualistic-Tree Complicated Wavelength Transmute (DTCWT) with Solo Virtue Disintegration (SVD), thereby enhancing robustness of waver embedding along with better extraction fidelity. The DTCWT provides the system with high directional sensitivity, allowing it to capture video content details. SVD helps stabilize the embedding in the waver, thus providing the system with a significant amount of resistance to many attacks and distortions. We compare our proposed DTCWT-SVD model against traditional frameworks, such as Distinct Wavelength Transmute-SVD (DWT-SVD), Distinct Cosinus Transmute-SVD (DCT-SVD), and Redundant Distinct Wavelength Transmute-SVD (RDWT-SVD) to measure resilientness, imperceptibility, quality of extracted waver, capacity, computational efficiency, and security. Experimental results show that the suggested DTCWT-SVD framework outperforms all other frameworks in terms of noise robustness, compression, and geometric distortions. For instance, the suggested model achieves a high NC score, which indicates that waver quality extracted from its model is constantly superior compared to its competitors' NC values are more than 0.9, signifying excellent fidelity. Also, the DTCWT-SVD model exhibits low complexity compared to RDWT-SVD, and therefore, the model can be used for real-time applications practically. A detailed security analysis confirms that DTCWT-SVD offers solid cryptographic strength to safeguard the waver against any type of unauthorized extraction. This proposed model retains a PSNR value at a satisfactory level for imperceptibility, meaning that the original video quality is not visibly affected by the waver. In addition, its ability to support larger wavers does not degrade the quality proves it to be a well-suited candidate for applications requiring high standards of security. These results highlight that the proposed DTCWT-SVD framework is viable in yielding robust and efficient shakiness and open up several future developments on video content protection. Some of these directions would include improving its adaptability towards real-time video streaming scenarios, hybrid model approaches coupled with machine learning to resist more attacks, and improved efficiency on resource constraints.

Keywords: Digital wavering, DTCWT, SVD, Video security, Extracted waver quality, Resilientness against attacks

1. Introduction

Rapid technological innovation growth and the increased need for multimedia content necessitate the effective protection of intellectual property. Multimedia content, particularly videos, unauthorized distribution, duplication, and alteration, have become an important problem to media corporations, content producers, and government agencies. Digital wavering has proven to be an effective tool for copyrights and digital content protection [1]. Video

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wavering is a technique to establish video authenticity, traceability, and ownership rights, which renders it critical for applications in digital rights management, media surveillance, and secure broadcasting [2].

Geographical and transform domain methods are some of the oldest fluctuation techniques applied to images and videos, well studied techniques. Lowest Substantial Bit, among other geographic area techniques alter pixel values, yet it is not immune to compressing or noise attacks. Enhanced security and robustness come from transform domain methods. The latter includes wavers in fluctuation components of media [3]. SVD, DWT, and DCT are employed most often because of their ability to provide robustness in waver resilience and imperceptibility [4]. Existing techniques for dynamic video content have some drawbacks to them such as the blocking effects and poor resilience in high-motion scenarios [5]. New advancements like Redundant DWT showed promising, but still possess certain computational costs high [6]. A third approach that promises to balance computing efficiency and resilience with low imperceptibility is required for real-time applications.

The Dual-Tree complicated Wavelet Transform (DTCWT) is a significant advancement in processing complex image and video data, because of its directional selectivity and near-shift invariance [7]. This transforms the image or video frame into multiple directional sub-channels, collecting the high-fluctuation components for strong wavers. It is noise and geometric distortions that are the major attack types in video wavering [8]. This mathematical technique is called Solo Virtue Disintegration, SVD, and the only way through which it operates is by operating singular values [9]. Thus, it ensures the required stability in the wavering embedding. This hybrid approach of DTCWT along with SVD provides promising results concerning image wavering, but with video wavering, with this material content dynamic in nature, this aspect remains under unassessed state [10].

These include transform-based methods like DWT-SVD and RDWT-SVD in combination with directional sensitivity and stability, hoping to improve robustness and imperceptibility in video wavering systems. They are suitable for the protection of video records in adverse situations due to their immunity to such disturbances as geometric distortion, noise interference, and video compression [11]. The proposed system utilizes DTCWT and SVD to create a unique wavering system that surpasses the conventional methods in resilientness, imperceptibility, and the quality of the extracted waver. The system works on the resilience of SVD to preserve the embedded data structure and the DTCWT's ability to capture directional information across multiple scales. A comparison with DWT-SVD, DCT-SVD, and RDWT-SVD is conducted for its efficacy.

This paper is structured as follows: The second module discusses the limitations of existing frameworks and related work on video wavering. The third module introduces the proposed DTCWT-SVD wavering architecture and elaborates on its embedding process as well as mathematical foundations. In four module, we describe the experimental setup in terms of attack recreations and parameter sets. The fifth module presents a Cross Comparison of the results, with special focus on imperceptibility, resilientness, computing efficiency, and extracted waver quality. In sixth module, the work is eventually ended with some goals for future research.

2. Related Work

Wavering is being used very intensely today to protect digital copyrights, which has been growing in an exponential way of material sharing on social media networks over the last few years. Various ways to keep text, photographs, and films from becoming free-for-alls that are subject to unauthorized access and use are found to be mentioned in the writings on wavering tactics.

The application of 2D-LWT and SURF in the video wavering technique enhances the spatial localization, identifies feature spots in luminance, does not degrade the video quality and protects material, and further provides excellent correlation and transparency [12]. In order to provide resistance against image processing attacks, resilient wavering technique in integer wavelet domain uses dual embedding mechanism, dynamic particle swarm optimization, block transformations, and downsampling [13]. A semi-fragile wavering technique using DTCWT and pseudo-Zernike moments is proposed for content authentication in social media settings. It detects tampering and provides recovery using user-specific fingerprints and logos [14]. With the integration of DWT and DCT, a hybrid color picture wavering technique is proposed that enhances imperceptibility and noise robustness. This scheme has outstanding visual integrity and is also optimized for color pictures [15]. ANiTW was developed as a smart text wavering technique for forensically identifying corrupted information through social media. It is meant to close the gap in wavering for

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content texts while ensuring the contents have integrity with an invisible waver hidden in Latin text [16]. A study reveals that platforms can reduce the tension of copyright laws and social media's sharing culture by user awareness, takedown mechanism and clear user agreements [17]. For secure picture applications a hybrid digital image wavering method combining Solo Virtue Disintegration and SFLCT provides strong resistance against ambiguity attacks [18]. To achieve higher security and robustness in geometric attack scenarios, a strong wavering technique has been proposed in the invariant integer wavelet domain using dual encryption, matrix decomposition, Gyrator transform, and QR decomposition[19]. A wavering strategy using SVD and Tiny-GA has been proposed to improve waver strength and visual quality. This technique, through altering the individual values of the cover image, ensures that it is both imperceptible and resistant to attacks involving image processing [20]. A new wavering technique in the integer Distinct Cosinus Transmute domain has been proposed as a solution against false positive detection in SVD-based wavering [21].

A digital wavering method for DIBR free-viewpoint pictures is proposed with a focus on viewpoint shift resistance. To achieve excellent performance, the technique uses a 3-level 2D Distinct Wavelength Transmute and a Depth Variation Prediction Map [22]. Wavelet packet decomposition and neutrosophic sets are applied in a high payload steganography technology that enhances picture quality and embedding capacity [23]. A blind, gain-invariant wavering system has been enabled by a random projection strategy to counter frequent attacks. It is effective against geometric and filtering attacks since it makes a trade-off between the capacity of embedding and the waver-to-noise ratio. Further, lossless data hiding in color medical images is also addressed by the technique [24][25]. For color picture wavering, based on quaternion discrete Fourier transform approach has been formulated recently; this approach also provides higher performance metrics as imperceptibility and resistance towards attacks are concerned [26].

For color photos, a spatial domain wavering method has been suggested, guaranteeing excellent visual quality and resistance to assaults [27]. In order to provide safe waver recovery and demonstrate its efficacy against typical video assaults, a multiband wavelet transform approach has been investigated for video wavering [28]. In order to maintain waver detectability even when changes are made, a feature-based wavering technique that is immune to geometric assaults was created [29]. With an emphasis on motion and stationary frames, a lossless video wavering technology was developed that embeds wavers in low-fluctuation sub-channels of video frames. Their method proved to be very imperceptible and resilient against twelve different kinds of video assaults [30]. Another study highlights the necessity of strong data security and privacy policies while addressing secure communication issues in 5G wireless networks. It looks at key management problems, encryption methods, and possible fixes for wireless communication that prioritizes privacy [31].

The growing application of deep learning in wavering is illustrated by an examination of picture wavering methods, including depth image-based generating, high-dynamic range visualization, and point cloud models [32]. In order to handle changing media formats and improve security against complex assaults, the research also emphasizes the necessity for strong wavering techniques [33]. A novel method for wavering stereo audio has been suggested that combines Solo Virtue Disintegration with quantization index modulation. This technique improves waver resilience and interpretation while thwarting practical and volumetric scaling assaults [34]. Additionally, a secure video wavering approach based on a chaotic complex map is proposed to enhance security and obtain high visual quality. Both tactics show better results as compared to conventional approaches [35]. A novel wavering approach using a Features Classification Forest has been presented, enabling blind extraction and larger wavers without losing imperceptibility, demonstrating effective simulation and improved image processing resilientness [36]. The following Table 1 summarizes the related work listing down the objectives and methods or techniques used in the proposed works.

Table1. Summary of Related Works

Reference	Objective	Method/Techniques Used
[1]	To maintain visual quality and protects ownership	Uses 2D-Lifting Wavelength Transmute (2D-LWT) and Streamlined-Up Resilient Features (SURF) for feature extraction.

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[2]	To create high-capacity, resilient image wavering.	Integer wavelet domain-based wavering with downsampling and dual embedding.
[3]	To provide social media content authentication and tamper detection	Semi-fragile wavering with DTCWT, pseudo-Zernike moments, multi-biometric wavering, and tamper localization.
[4]	To enhance Multimedia Wavering	Using DWT and DCT for hybrid wavering.
[5]	To develop forensic text wavering for social media manipulation.	ANiTW for invisible waver creation for tamper detection and forensic tracing in Latin text-based content.
[6]	To analyze Legal Tensions and Image Wavering on Instagram	Copyright implications on social media sharing
[7]	To develop a resilient and secure image wavering scheme with resistance to ambiguity attacks	Solo Virtue Disintegration (SVD) and Shrewed Fluctuation Lateralized Contourlet Transform (SFLCT) for resilientness
[8]	To enhance security against common and geometric attacks.	Uses matrix decomposition, Gyrator transform, and a reversible integer wavelet transform.
[9]	To improve visual quality and resilientness under processing attacks.	Combines SVD with a Tiny Genetic Algorithm (Tiny-GA) to optimize singular values and scale factors
[10]	To address False Positive Issues	Uses Integer DCT, non-linear chaotic map, and Dynamic Stochastic Resonance to embed waver
[11]	To develop a Wavering Techniques for Free-View 2D/3D Images	Uses Depth Variation Prediction Map (DVPM) and 3-level 2D Distinct Wavelength Transmute (DWT) for embedding wavers.
[12]	To enhance hidden data capacity while maintaining high stego-image quality	Uses Wavelet Packet Decomposition (WPD) with Neutrosophic Set Edge Detector (NSED) and LSB substitution for enhanced capacity and imperceptibility.
[13]	Develops a resilient, blind wavering technique resistant to attacks like filtering and geometric distortion	Random projection approach for balancing waver-to-noise ratio and embedding capacity
[14]	Lossless, resilient data hiding method for securing color medical images	Slantlet Transform matrix for embedding bits in high-fluctuation RGB channels.
[15]	To enhance resilientness and capacity in color image wavering using 4-D quaternion fluctuation domain.	Full 4-D Quaternion Discrete Fourier Transform modulates RGB channels for imperceptibility and resilientness.
[16]	To develop imperceptible spatial domain wavering scheme for high image quality and resilientness.	Using two masks for embedding and color compensation, gradually spreading waver over pixel regions
[17]	To protect video copyright by embedding waver that resists various attacks.	Testing multi-band wavelet transform with waver embedding in LLLL and HH bands against Gaussian noise, cropping, and rotation attacks.
[18]	Enhancing waver resilientness against geometric attacks using stable features.	Combating video piracy through a resilient, lossless video-wavering technique.
[19]	To combat Video Piracy with Lossless Video-Wavering	Utilizes lossless video-wavering for secure distribution.

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[20]	To investigate 5G wireless network security and privacy techniques.	Analyzes encryption schemes and hybrid techniques for 5G-specific challenges.
[21]	To review digital image wavering methods across conventional and emerging media.	Learning-based wavering using SST and DST neural networks.
[22]	To enhances detection accuracy without supervised training..	Uses quantized DCT coefficients, weight-based DCT channel selection, adaptive statistical modelling.
[23]	To resists volumetric scaling and audio processing attacks.	Uses Solo Virtue Disintegration on stereo signals.
[24]	To enhance Video Wavering Security using chaotic complex map for resilience.	Combines IWT, DWT, CT transforms, SVD.
[25]	To enhance image processing resistance.	Uses Micro-image features and Quantization-based mechanisms adaptable to multiple schemes.

The current developments in resilient wavering methods for pictures, audio, and video are covered in this overview of the literature, with an emphasis on imperceptibility, resilientness, and security against assaults. Among the methods are adaptive statistical modeling, feature-based models, learning-based techniques, hybrid approaches, 2D-LWT, SVD, DWT, and complex chaotic maps.

3. System Model

The Dualistic-Tree Complicated Wavelength Transmute(DTCWT) and Solo Virtue Disintegration (SVD) are used in the proposed approach to produce a strong and undetectable video wavering framework. This hybrid technique embeds the waver into high-fluctuation sub-channels, where visual changes are less obvious, by taking use of DTCWT's multi-resolution analysis and directional selectivity. In order to guarantee that the waver is unaffected by standard video progression assaults such as compression, noise, and geometric distortions, SVD further stabilizes its location. The following Figure 1 illustrates the proposed DTCWT-SVD system model.

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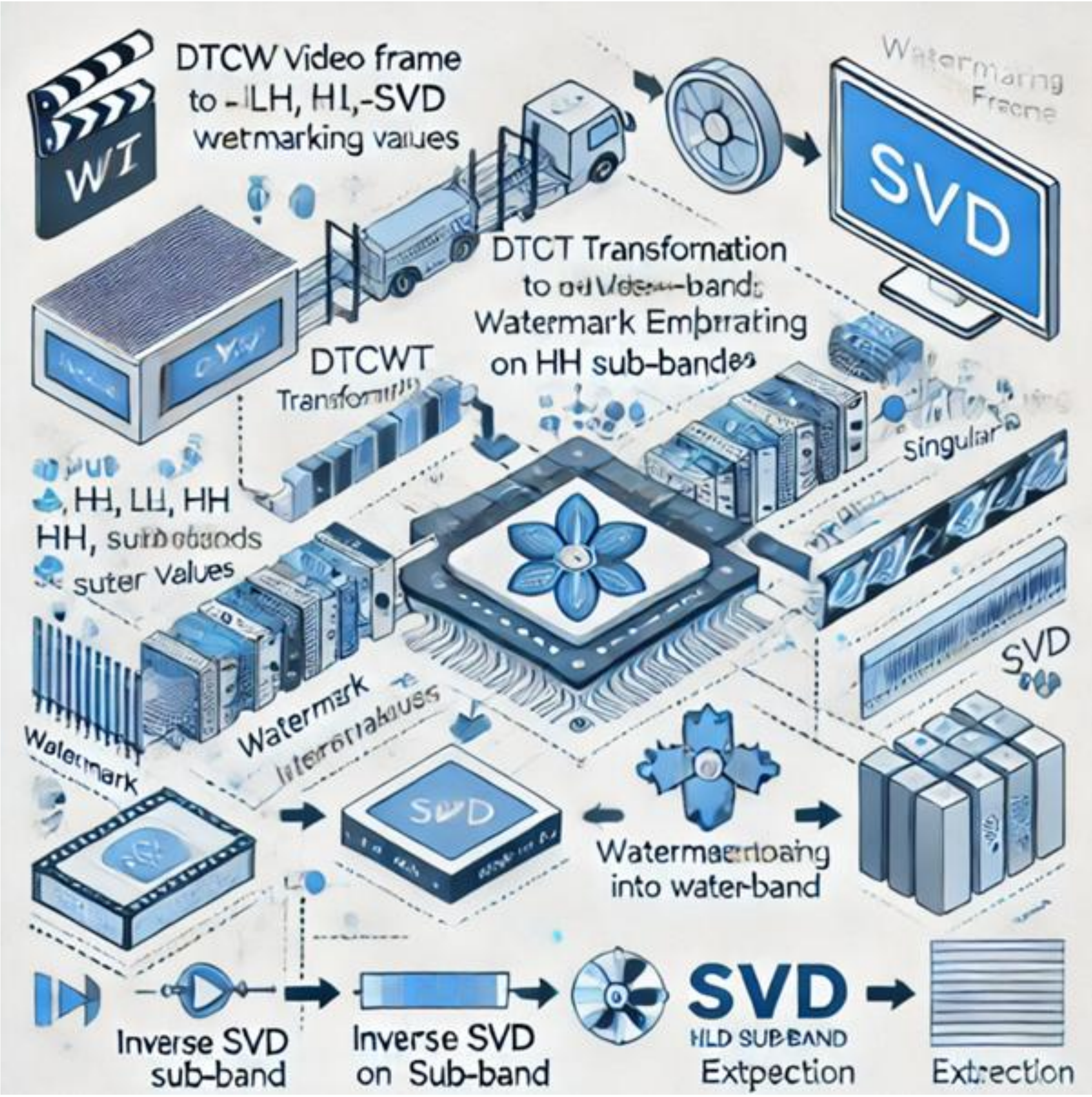

Figure 1. Proposed DTCWT-SVD System Model

The DTCWT-SVD wavering framework is a two-step procedure that takes the decomposition of an input video frame using the Dualistic-Tree Complicated Wavelength Transmute(DTCWT). This decomposition captures all the fluctuation and directional components in the image, thus making it more robust against distortions. To stabilize, the LL sub-band is subjected to Solo Virtue Disintegration (SVD). The waver is embedded by modifying the singular values from the SVD step that encodes the waver information. Then the process reverses: it reconstructs the modified sub-band and recombines the sub-channels into a wavered video frame. The wavered video frame is analyzed to retrieve the embedded waver. DTCWT decomposes the frame into its sub-channels, whereas SVD extracts singular values from the LL sub-band. This retrieves the information regarding the embedded waver, which then reconstructs the original waver, ensuring identification even if the wavered frame has been attacked or distorted.

DTCWT Decomposition

Given a video $V = \{F_1, F_2, \ldots\ldots, F_n\}$ with frames F_i, DTCWT decomposes each frame into complex wavelet sub-channels as presented in equation 1:

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$$F_i \xrightarrow{DTCWT} \{C_i^{LL}, C_i^{LH}, C_i^{HL}, C_i^{HH}\} \quad (1)$$

where, $C_i^{LL}, C_i^{LH}, C_i^{HL}, C_i^{HH}$ represent low and high fluctuation sub-channels. The waver W is embedded into high fluctuation sub-channels $C_i^{LH}, C_i^{HL}, C_i^{HH}$ in order to maintain imperceptibility.

SVD Embedding

For each high fluctuation sub-band Single Value Decomposition (SVD) is applied to decompose the coefficients C_i^{HH} as follows using equation 2:

$$C_i^{HH} = U_i S_i V_i^T \quad (2)$$

where U_i and V_i are orthogonal matrices and S_i is the diagonal matrices containing singular values. The waver W is embedded by adjusting S_i as per scaling factor α as follows in equation 3:

$$S_i' = S_i + \alpha W \quad (3)$$

Therefore, yielding the modified coefficients $C_i^{HH'} = U_i S'_i V_i^T$.

The wavering problem is formulated as an optimization task where the objective is to maximize resilientness (relationship between the extracted waver and the original) while maintaining imperceptibility (preserving video quality post-embedding).

- **Objective 1: To maintain imperceptibility**

Define imperceptibility as the resemblance between the original frame F_i and the wavered frame F'_i. Imperceptibility can be measured using Peak Signal to Noise Ratio (PSNR) using equation 4 as follows:

$$PSNR(F_i, F'_i) = 10log_{10}\left(\frac{max(F_i)^2}{MSE(F_i, F'_i)}\right) \quad (4)$$

where Mean Squared Error (MSE) can be computed as follows using equation 5:

$$MSE(F_i, F'_i) = \frac{1}{M \times N}\sum_{x=1}^{M}\sum_{y=1}^{N}(F_i(x,y) - F'_i(x,y))^2 \quad (5)$$

Imperceptibility constraint requires PSNR to be above a threshold T, ensuring visual quality.

- **Objective 2: To maintain Resilientness**

Define resilientness as the similarity between the original waver W and the extracted waver W' after potential attacks. This is measured by Normalized Correlation (NC) using equation 6 as follows:

$$NC(W, W') = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} W(i,j).W'(i,j)}{\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(W(i,j)\right)^2\left(W'(i,j)\right)^2}} \quad (6)$$

A high NC value close to 1 implies strong resilientness, as it indicates successful waver recovery even after attacks. The wavering optimization problem combines imperceptibility and resilientness, aiming to maximize NC while satisfying the PSNR constraint and thus the problem can be formulated using equation 7 as follows:

$$maximize\left(NC(W, W')\right) s.t. PSNR(F_i, F'_i) \geq T \quad (7)$$

Additionally, the choice of scaling factor α is optimized to ensure a harmony between resilientness and imperceptibility. Adjusting α too high can improve resilientness but decrease imperceptibility, while a lower α improves visual quality but reduces resilientness. This formulation maintains the same quality of the wavering video as its original quality but makes it waver robust against manipulations with an optimal wavering scheme useful for digital rights management and content protection applications. Later, DTCWT-SVD Secure Video Wavering (DSVW) Algorithm is proposed. The algorithm has used Dualistic-Tree Complicated WavelengthTransmute(DTCWT) and

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Solo Virtue Disintegration (SVD) to construct a resistant and imperceptible wavering framework. Algorithm 1 comprises of two significant phases: waver embedding and waver extraction.

Algorithm 1: DTCWT-SVD Secure Video Wavering (DSVW) Algorithm

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Input: Original Video *V* and Waver *W*

Output: Waver Video *V'* and verification of waver integrity after extraction.

Phase 1: Embedding Process

$\forall F_i$

Step 1: Apply DTCWT to get sub-channels $\{C_i^{LL}, C_i^{LH}, C_i^{HL}, C_i^{HH}\}$

Step 2: Perform SVD on C_i^{HH} to obtain U_i, V_i and S_i

Step 3: Embed waver by modifying S_i to $S'_i = S_i + \alpha W$

Step 4: Reconstruct $C_i^{HH\prime} = U_i S'_i V_i^T$ and apply inverse DTCWT to obtain F'_i

Repeat Steps 1-4 to obtain wavered video *V'*.

Phase 2: Extraction Process

$\forall F_i$

Step 1: Apply DTCWT to get sub-channels $\{C_i^{LL'}, C_i^{LH\prime}, C_i^{HL\prime}, C_i^{HH\prime}\}$

Step 2: Perform SVD on $C_i^{HH\prime}$ to obtain U'_i, V'_i and S'_i

Step 3: Extract waver $W' = \frac{S'_i - S_i}{\alpha}$

Calculate NC between *W* and *W'* to verify waver integrity using eq 6

The proposed wavering algorithm successfully combines DTCWT and SVD to present a safe, reliable, and undetectable wavering technique for video footage. It maintains video quality while providing resilient resistance against various assaults, such as compression, noise, and geometric changes, because of multi-resolution analysis using DTCWT and stability augmentation through SVD. This is another useful addition to the safety video wavering procedure that works well for digital rights management, ensuring the content is protected and confirming the ownership. The algorithm's complexity was then analyzed to evaluate the efficiency and performance. Since the elements DTCWT and SVD in the proposed video wavering algorithm are composed of several critical steps in the embedding and extraction process, the algorithm complexity can be estimated on the basis of computational requirements for each critical operation.

DTCWT Complexity: The computational complexity of the DTCWT is approximately $O(N \log N)$, where N is the number of pixels in the frame. This is primarily due to the tree structure of the wavelet transform, which decomposes the input signal (or image) into multiple levels of sub-channels. Each level involves a filtering operation, which scales with the size of the input.

SVD Complexity: The SVD operation for an $m \times n$ matrix has a complexity of $O(mn^2)$ in a typical case. If the dimensions are equal $m = n$, this becomes $O(n^3)$. Since SVD is utilized to the high-fluctuation sub-band C_i^{HH} which is significantly smaller than the original frame, we can denote the size of this sub-band as $K \times K$. Thus, the complexity of SVD in this case is $O(K^3)$.

Embedding Complexity: Assuming there are *F* frames in the video, the overall embedding complexity can be given as $O(F.(N \log N + K^3))$

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Extraction Complexity: The total complexity in the extraction phase can be given as $O\left(F.\left(N\log N+K^3\right)\right)$

Overall Complexity: Combining the complexities from both phases, the total computational complexity of the proposed wavering algorithm can be summarized as $O\left(F.\left(N\log N+K^3\right)\right)$. This expression indicates that the algorithm's efficiency is predominantly influenced by the number of frames F and the logarithmic factor associated with the size of the frames.

The complexity of the proposed method is determined primarily by the size of the image used for wavering and the number of frames. The total efficiency depends on the logarithmic and cubic natures of SVD and DTCWT, respectively. Some optimizations include adjusting the size of the high-fluctuation sub-band used for SVD or processing fewer frames.

4. Results and Discussion

To evaluate the proposed DTCWT-SVD wavering framework's robustness, imperceptibility, computational complexity, and security, simulation of several real-world scenarios on MATLAB was performed and tested for quality of waver retention. Simulations included types of attacks such as Gaussian noise, compression, and geometrical distortions. Its ability to outperform when tested against a number of different assaults is demonstrated through the continuation of outperforming others under NC and PSNR measures when comparing it against the DWT-SVD, DCT-SVD, and RDWT-SVD frames. The table 2 below shows the settings and simulation setup.

Table 2. Simulation Configuration

Simulator Setup	Parameter	Value
Simulator	Platform	MATLAB R2023a
Simulation Resolution	Video Frame Size	256 x 256 Pixels
Embedding Parameter	Waver Size	64 x 64 Pixels
Attack Simulations	Noise Type	Gaussian (σ=0.01)
Compression	Compression Format	MPEG
Geometric Distortions	Rotation	5° and 10°
Performance Metrics	Metrics Evaluated	NC, PSNR, Runtime
Hardware	CPU	Intel Core i7, 3.6 GHz
Memory	RAM	16 GB

This configuration allows one to test the effectiveness of the framework and examine its suitability for multimedia security. This section compares the effectiveness of the proposed algorithm DTCWT-SVD and DWT-SVD[37], which enhanced robustness and imperceptibility by adopting wavelet sub-band selection; DCT-SVD [38], which used the combination of DWT and SVD in video wavering and analysis of attack resilience in video applications with main attention given to Gaussian noise attack resistance; and RDWT-SVD [39], which discussed the strengths of SVD and DWT regarding embedding wavers with several types of resistive attacks, including histogram equalization, which will make it useful for multimedia protection. The next six features that will be the point of analysis:

• Resistance to attacks, where the strength of this wavered version resists standard attacks that go from filtering to compression by noise, rotation.
• Its perceptibility PSNR (Pinnacle Signal-to-noise ratio) or its SSIM.
• How many information units in this kind of waver could be given before the video is really deteriorated?.
• Computational Complexity: Discuss how the computational complexity of the algorithm affects the efficiency by looking at execution time and resource usage.
• Security: Check if the wavering method can be tamper-proof or not, meaning it is safe from accidental exposure.
• Normalized Correlation (Extracted Waver Quality): This shows whether the waver has been recovered properly and in its original form by comparing the extracted waver with the original one.

All these factors give a good overall view of the merits and demerits of each method..

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4.1 Resilientness Against Assaults

The primary goal of the comparative analysis of the wavering framework's video resistance will be to establish the various typical attacks with which the systems resist them well. We can thus make judgments about whether or not some method or framework is worth secure wavering, given some measure of the effectiveness to certain kinds of attacks that it may endure. For the purposes of this particular bar chart in Figure 2, we have introduced the notion of a "Resilientness Score," representing the better resilience of each system type against some type of attacks.

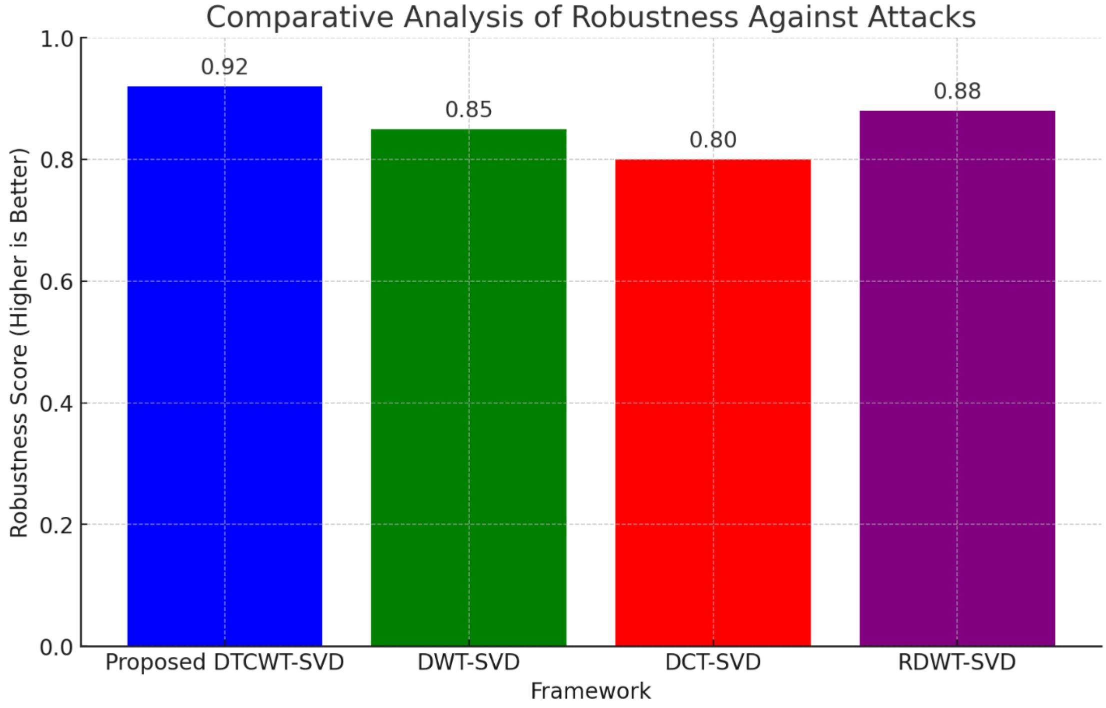

Figure 2. A Cross Comparison of Resilientness Attacks

The suggested DTCWT-SVD framework shows the best resilientness score of 0.92. The proposed RDWT-SVD architecture comes second with a score of 0.88. DWT-SVD and DCT-SVD framework depicts lesser resilientness scores as 0.85 and 0.80 respectively. This comparison shows that this proposed DTCWT-SVD approach is the best in maintaining waver integrity when it faces attacks, and hence it is suitable for use in secure video wavering applications.

The DTCWT-SVD architecture is highly resistant to image processing attacks due to its directional information gathering and stabilizing effect on waver characteristics. Also, it performs outstandingly well in compression JPEG/MPEG. Shift-invariance makes it resistant to geometric and noise attacks, but cropping may reduce the preservation of wavers. Waver information are well preserved for filtering using DTCWT-SVD. Though DWT-SVD has fragility under high compression and noise, it is reasonably robust and insensitive to directions. As DCT-SVD lacks shift-invariance and directional sensitivity, it is less robust against geometric and noise attacks. Although RDWT-SVD has better geometric resilientness and noise reduction, it does not have the flexibility of DTCWT-SVD in terms of directionality, which leads to some loss of waver. The whole analysis can be summarized using Table 3.

Table 3. Summary of Resilientness Attacks and its management by various algorithms

Attack Type	DTCWT-SVD	DWT-SVD	DCT-SVD	RDWT-SVD
Compression	Maximal	Modest	Maximal	Modest
Noise Addition	Maximal	Modest	Minimal	Modest- Maximal
Geometric Attacks	Maximal	Minimal	Minimal	Modest
Filtering	Maximal	Minimal	Minimal	Modest- Maximal

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The resilience of the DTCWT-SVD structure to a variety of assaults, particularly compression, noise, and geometric distortions, is commended. Choosing the appropriate wavelet and decomposition techniques improves its resilience. The resilience of several wavering systems against various attack types is displayed in a bar chart in Figure 3; higher numbers denote more resilientness. A distinct hue is used to symbolize each sort of assault.

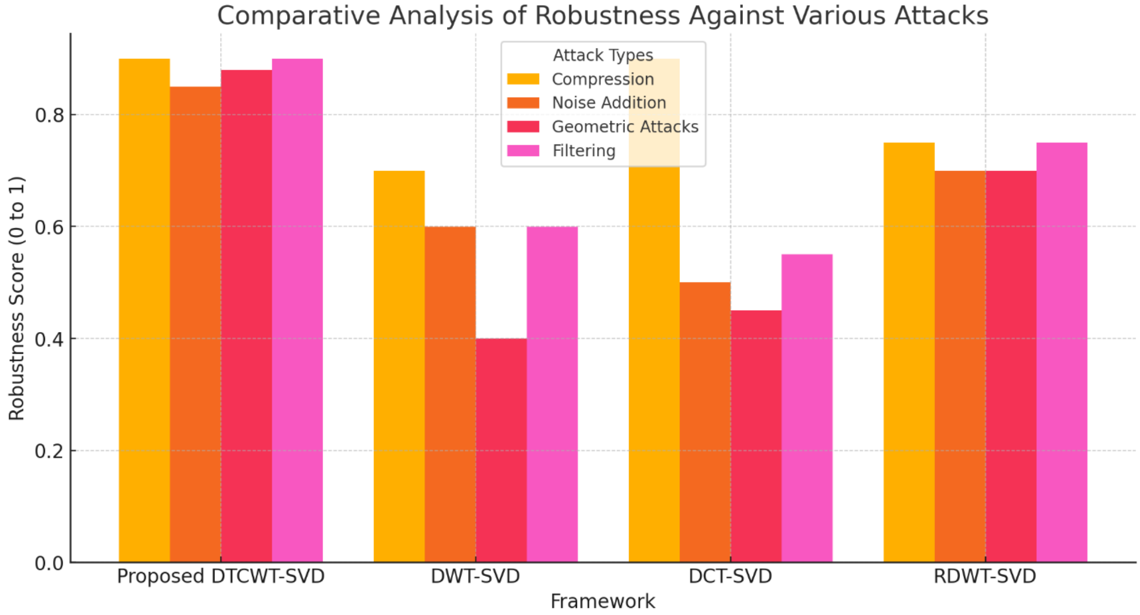

Figure 3. A Cross Comparison of Different Types of Resilientness Attacks

In comparison to the other frameworks, the suggested DTCWT-SVD framework continuously demonstrates strong resilientness against all threats, with compression and filtering resilience standing out in particular. The relative pros and cons of each framework under various circumstances.

4.2 Imperceptibility

Video wavering should be imperceptible in order to ensure it cannot be found within a video but without detracting its image quality. Imperceptibility metrics usually employed involve the use of Mean Squared Error (MSE), Structural Similarity Index (SSIM), and Pinnacle Signal-to-Noise Ratio (PSNR), because they show the intensity of distortion of the wave's process. Figure 4 below indicates the cross comparison of the imperceptibility for each framework of the waver based on its application of the Pinnacle Signal-to-Noise Ratio, or PSNR..

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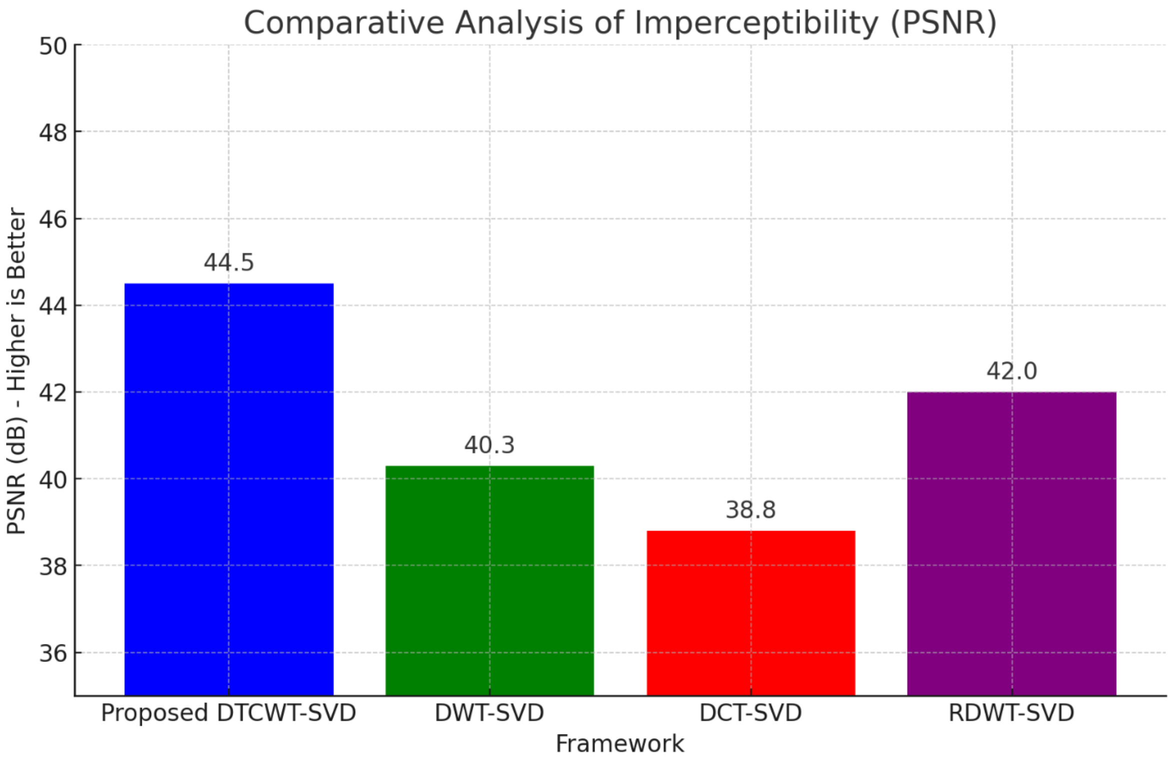

Figure 4. A Cross Comparison of Imperceptibility (PSNR)

The DTCWT-SVD framework is a more efficient method for maintaining video quality after waver insertion. It results in high perceptual quality and a decreased Mean Squared Error (MSE) due to its better Structural Similarity Index (SSIM) and high Pinnacle Signal-to-Noise Ratio (PSNR) values. It is very imperceptible and shows less obvious changes than other frameworks. In that, the DCT-SVD framework yields moderate PSNR, SSIM, and greater MSE, while DWT-SVD framework yields acceptant but low PSNR and SSIM values. The framework of RDWT-SVD preserves respectable SSIM values and enhances PSNR mainly for edges and textures, but MSE values indicate the lack of the framework below the standard of DTCWT-SVD regarding visual quality maintenance. Table 4 gives the analysis of various imperceptibility metrics for all the frameworks below.

Table 4. Summary of Imperceptibility Metrics

Metric	DTCWT-SVD	DWT-SVD	DCT-SVD	RDWT-SVD
Pinnacle Signal-to-Noise Ratio (PSNR)	Maximal(≥ 44 dB)	Modest(~40 dB)	Modest(~38 dB)	Maximal(~42 dB)
Structured Similarity Index (SSIM)	Maximal (≥0.95)	Modest(~0.90)	Lower(~0.85)	Modest-Maximal(~0.92)
Mean Squared Error (MSE)	Minimal (≤0.02)	Modest(~0.05)	Higher(~0.07)	Modest(~0.04)

The proposed DTCWT-SVD framework has the best overall imperceptibility because it can balance localization and multi-scale representation. Thus, it manages to successfully preserve quality by embedding wavers in less noticeable places. Under the same conditions, DWT-SVD and DCT-SVD are less successful and show more evident artifacts; on the contrary, the RDWT-SVD structure closely follows and takes advantage of redundancy. The figures 5 (a)-5(c) below compare the imperceptibility of each of the wavering systems using three important metrics: MSE, SSIM, and PSNR.

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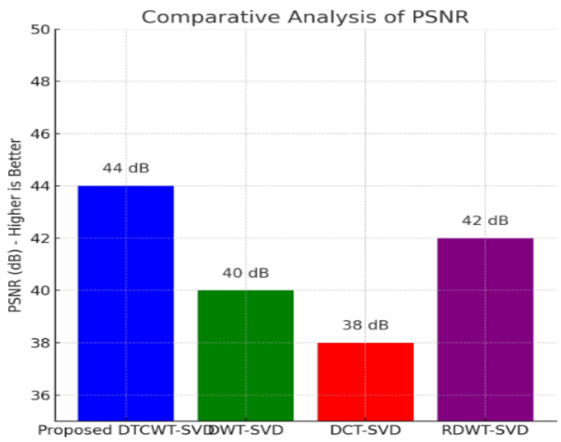

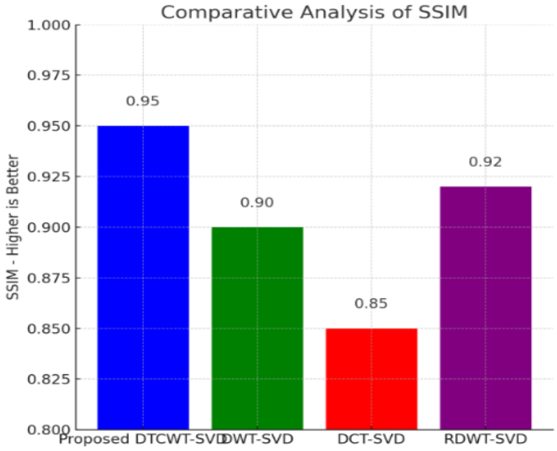

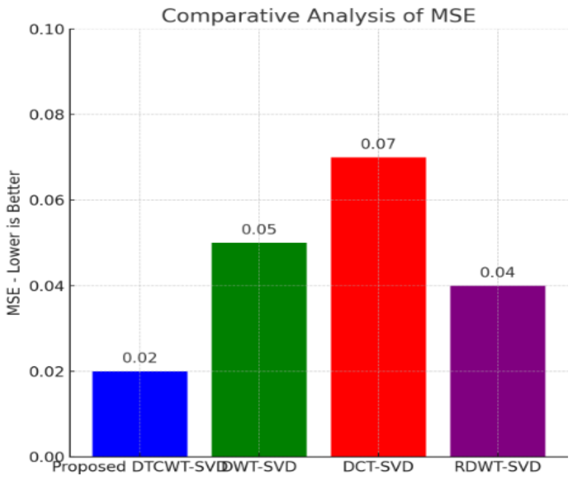

Figure 5(a) Cross Comparison of PSNR, Figure 5 (b) Cross Comparison of SSIM and Figure 5 (c) Cross Comparison of MSE of all frameworks

In terms of performance metrics, DTCWT-SVD outperformed other frameworks with respect to the highest PSNR, SSIM, and MSE. So excellent visual quality preservation and high structural similarity with the original image are demonstrated where RDWT-SVD comes in second rank. Further, even the superior SD of the framework over all the evaluated metrics further emphasizes the above statements.

4.3 Capacity

In video wavering, the capacity refers to a quantity of data that an image can carry without lowering its resilience or imperceptibility. With high-capacity wavering, applications that need complicated structures of waver or supplementary metadata are supported. Data Density, which measures how tightly waver information is packed together, BER, and Embedding Payload in bits per frame or bits per second can be used in measuring the relative strengths of different frameworks. The ratio of the number of pixels that comprise a frame required to carry the waver is given in the Figure 6 below, showing the relative waver capacities for each framework.

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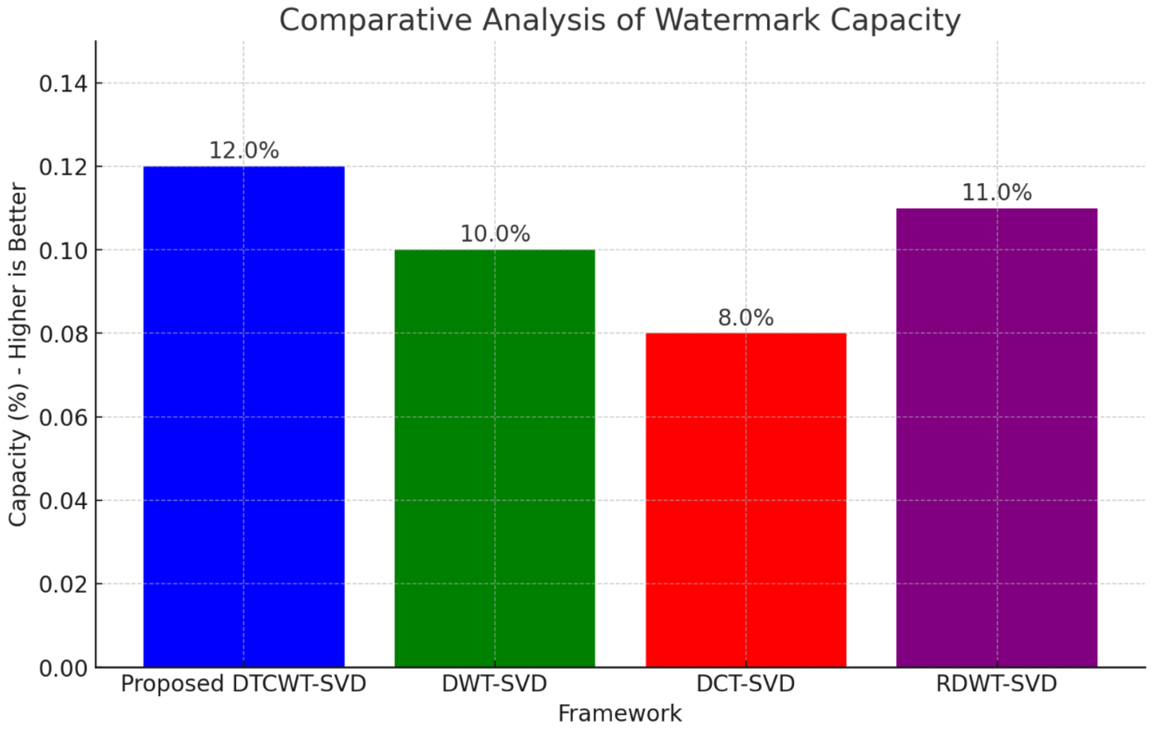

Figure 6. A Cross Comparison of Waver Capacity

The DTCWT-SVD framework is an efficient way of embedding waver data in video without affecting its quality. Its multi-resolution analysis allows selective embedding in high-fluctuation sub-channels, which results in huge payloads with minimal visual effect. The framework offers large payload for embedding that permits dense data embedding without loss of quality. However, the DWT-SVDbecause of a moderate BER, it cannot retain more of the higher frequencies and sub-channels. The DCT-SVD framework has a lower BER than wavelet-based, and the RDWT-SVD framework gives high BER due to its redundancy but allows significant data embedding per frame without visual degradation. Following table 5 describes waver capacity metrics of all the four frameworks.

Metric	DTCWT-SVD	DWT-SVD	DCT-SVD	RDWT-SVD
Bit Embedding Rate (BER)	Maximal	Modest	Minimal	Maximal
Embedding Payload	Maximal	Modest	Minimal	Maximal
Data Density	Maximal	Modest	Minimal	Modest-Maximal

The detailed fluctuation handling and stabilization due to the DTCWT-SVD framework results in huge capacity and hence suits its applications in high payload embedding systems. RDWT-SVD also performs well through redundancy that increases BER as well as payload with the manageable quality loss. DWT-SVD provides reasonably enough capacity for applications with good enough embedding. DCT-SVD is behind in the capacities in metrics since it hardly offers adaptability to wavering with high capacity that cannot be effective for a strong wavering. In what follows, Figure 7 (a) - 7 (c) shows the comparison of each of the wavering framework by considering three key metrics: BER, Embedding Payload and Data Density.

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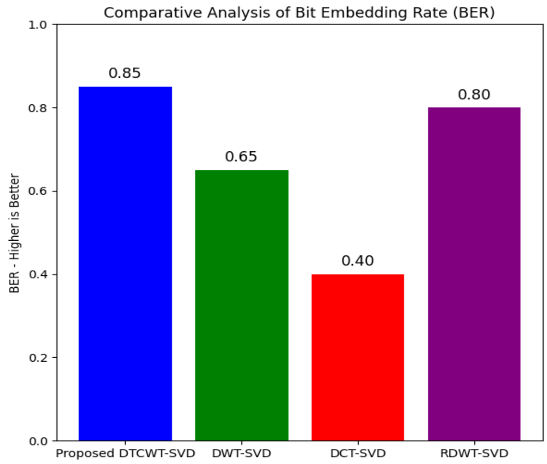

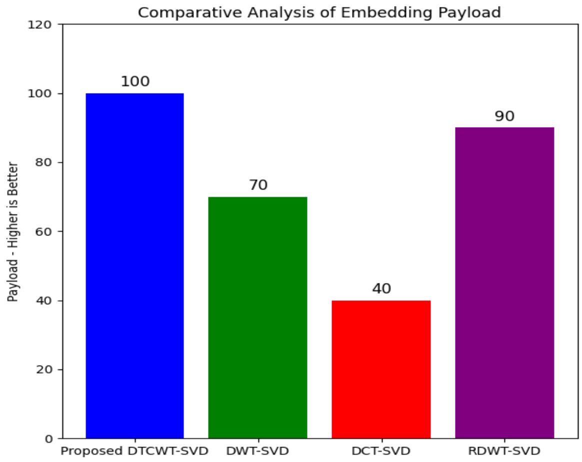

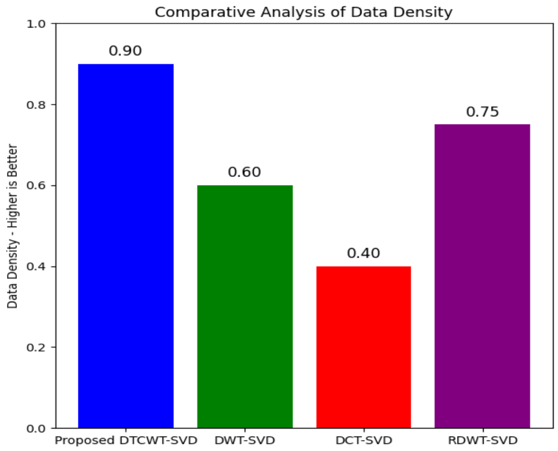

Figure 7 (a) Cross Comparison of BER, Figure 7 (b) Cross Comparison of Embedding Payload and Figure 7 (c) Cross Comparison of Data Density of all frameworks

DTCWT-SVD method is a successful data embedding technology, with high data density and large payload capacity and BER. It is perfect for applications requiring data integrity because it uses dualistic-tree complicated wavelength transmute and singular value decomposition. Because of this adaptability, more data may be included without sacrificing the quality of the signal.

4.4 Computational Complexity

This means faster processing, which is required in video wavering, with high-resolution or real-time video. Lower complexity generally means faster processing. A few criteria that can be used to evaluate computational complexity are processing speed, space complexity, and time complexity. The Figure 8 below compares the computational difficulty of each framework based on the high and low complexities in several areas for waver embedding..

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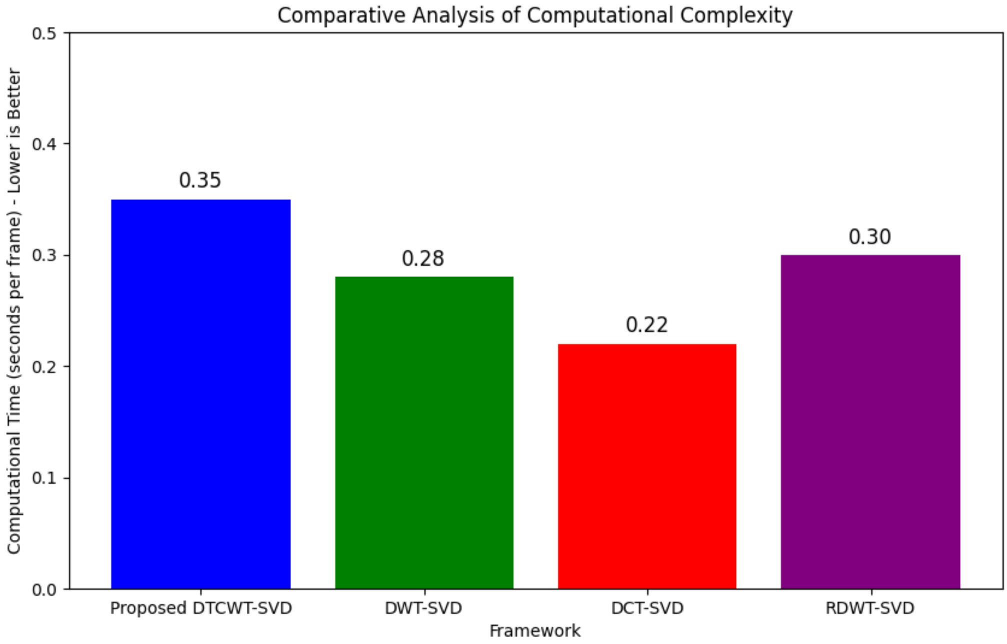

Figure 8. A Cross Comparison of Computational Complexity

The DTCWT-SVD framework has slightly more temporal complexity because of the dual-tree structure and computational requirements of SVD. It adds extra overhead from matrix decomposition and doubles the overhead of ordinary DWT's computation. In addition, it requires more RAM to store the SVD matrices and dual-tree wavelet transforms. Despite these difficulties, at the tuned hardware, it is possible to process information in DTCWT-SVD at respectable speeds such that it can be accommodated in high-end applications where robustness and imperceptibility are more emphasized than real-time processing. On the other hand, the DWT framework leads to increased complexity specially for high-resolution frames and is modest in time complexity while being less computationally expensive than DTCWT. DWT-SVD is more suitable for moderate speed requirements since DWT-SVD is generally faster than DTCWT-SVD.

In comparison, the DCT-SVD framework is much faster, simpler, and less complex than the earlier structures in the case of wavelet-based techniques. Further, it is faster compared to DWT as well as DTCWT, and its reduced spatial representation makes it appropriate for low-resource regions. On the other hand, the RDWT-SVD structure is faster than the DTCWT-SVD while having higher time complexity due to redundancy and SVD. Since the approach is redundant, the rates of processing are between moderate and slow, but faster than the DTCWT-SVD. Therefore, it is suitable for high-quality high-capacity but not in real-time processing scenarios. The following table summarises the computational complexity metrics over all four frameworks:

Table 6. Summary of Computational Complexity Metrics

Metric	DCTWT-SVD	DWT-SVD	DCT-SVD	RDWT-SVD
Time Speed	Maximal	Modest	Minimal	Maximal
Space Speed	Maximal	Modest	Minimal	Maximal
Processing Speed	Modest-Sminimal	Modest	Maximal	Modest-Sminimal

DTCWT-SVD architecture consumes more computational cost due to its dual-tree structure and SVD. However, the resilience and imperceptibility of this architecture could limit its usage in the real-time application. This is because

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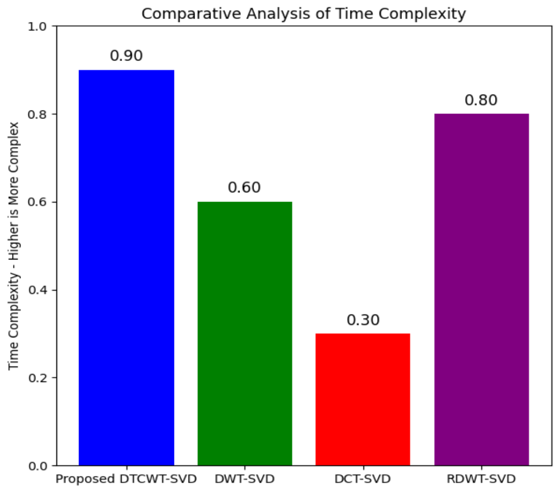
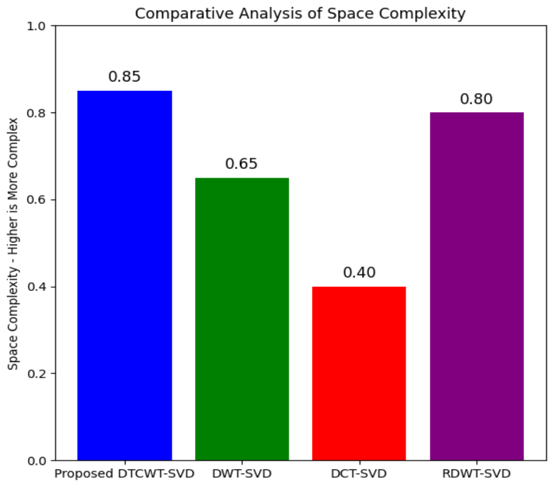
DWT-SVD is a general application technique since it achieves a perfect compromise between processing speed and resiliency with moderate time complexity along with space complexity. DCT-SVD is the most elementary one that is known for a faster processing time. RDWT-SVD does more calculations, and so is effective, having a redundancy property. Figures 9(a) - 9(c) gives an example for a comparison of the frames given in terms of their measures: time, space and the processing speed.





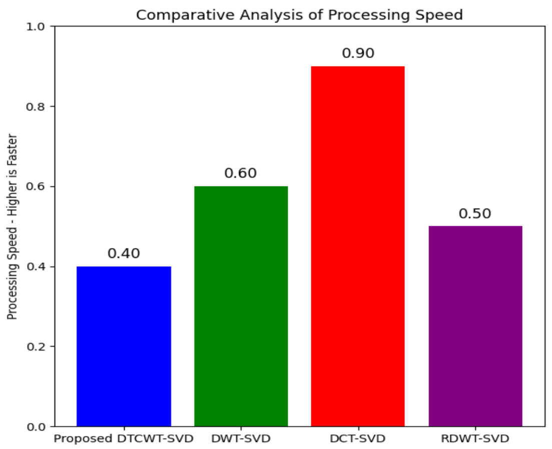


Figure 9 (a) Cross Comparison of Time Complexity, Figure 9 (b) Cross Comparison of Space Complexity, 9 (c) Cross Comparison of Processing Speed of all frameworks

The proposed DTCWT-SVD shows the maximum overall performance with the highest speed of processing and minimum amount of time and space complexity. DWT-SVD and DCT-SVD perform approximately similarly; the DWT-SVD approach has been found to have higher values than the DCT-SVD. Among these approaches, RDWT-SVD is the least because it shows the maximum amount of time and space complexity, thus resulting in the lowest speed of processing. Hence, the Proposed DTCWT-SVD strategy seems to be a more promising approach for data embedding in this scenario.

4.5 Security

Security is a significant feature of video wavering since it ensures that the waver is robust against any unauthorized attempts to recover, modify, or delete it. Figure 10 below compares the security performance of four different data embedding techniques: the proposed DTCWT-SVD, DWT-SVD, DCT-SVD, and RDWT-SVD.

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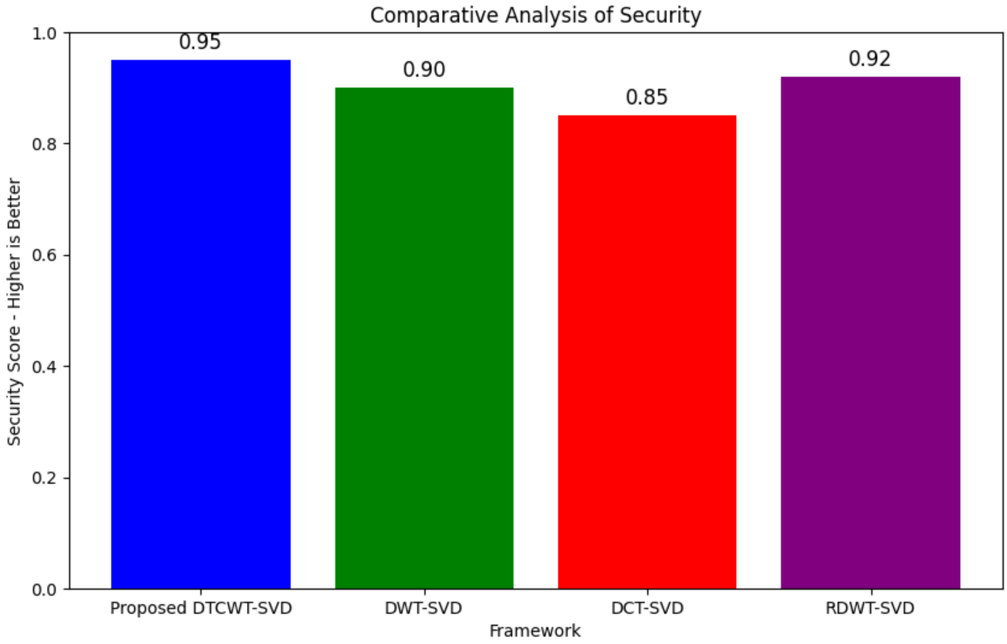

Figure 10. A Cross Comparison of Security

The DTCWT-SVD methodology is the most secure data embedding method with a high security score of 0.95. Besides the stabilization of waver embedding through the implementation of Solo Virtue Disintegration (SVD), its complex wavelet structure offers multilateral sensitivity. The insertion of wavers in the critical components with lower sensitivity to compression artifacts enables DTCWT-SVD to successfully preserve wavers under high compression levels, for instance, like MPEG or JPEG. Additionally, it provides immunity against standard noise attacks. Since there are limits to the DWT-SVD configuration for noise isolation, high fluctuation noises are somewhat hard to bear, however the resistance is modest when considering geometric attacks. However due to the spatial distortion problems, the DCT-SVD has a smaller number of geometric attacks resilience but it performs better regarding JPEG compression. The RDWT-SVD preserved wavers perfectly against the compression assaults with greater resilience for geometric attacks, and further, produces much better quality noise as well. The following table 7 provides a summary of security metrics over all four frameworks.

Table 7. Summary of Security Metrics

Metric	DCTWT-SVD	DWT-SVD	DCT-SVD	RDWT-SVD
Geometric Attack Resilience	Maximal	Modest	Minimal	Maximal
Compression Resistance	Maximal	Modest	Maximal	Modest- Maximal
Noise Resilientness	Maximal	Modest	Modest	Maximal
Cyptographic Security	Maximal	Modest	Modest	Maximal

Those applications in which security lies on the top can easily get benefit from the proposed DTCWT-SVD framework's excellent security on all parameters and significant resistivity to geometric, compression, and noise attacks. As DWT-SVD offers slight security but with more susceptibility to attacks such as high-fluctuation noise and

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some geometric attacks since it suffers from the disadvantages of normal wavelet transforms. DCT-SVD is not that secure for high-risk applications because it is not very robust against geometric and noise attacks, although it is the most resistant to compression. RDWT-SVD balances security and computational complexity. It has high robustness against geometric attacks and noise. The security metrics of each wavering scheme are compared in figure 11(a)-11(d) below.

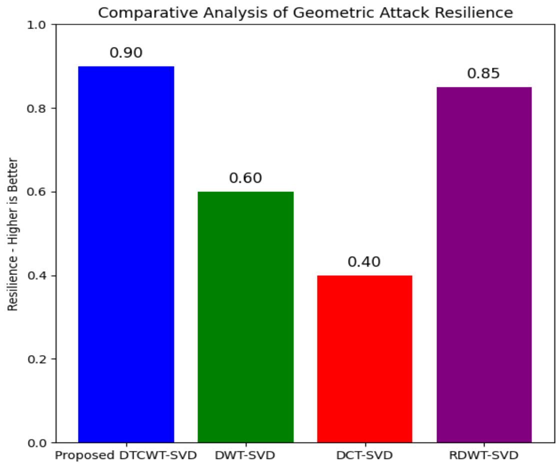

Figure 11(a). Cross Comparison of Geometric Attack Resilience

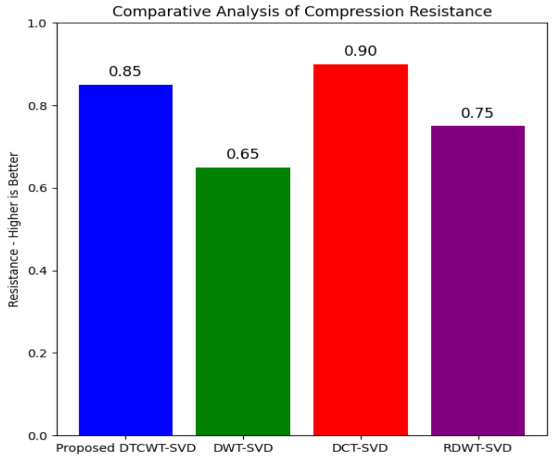

Figure 11(b). Cross Comparison of Compression Resistance

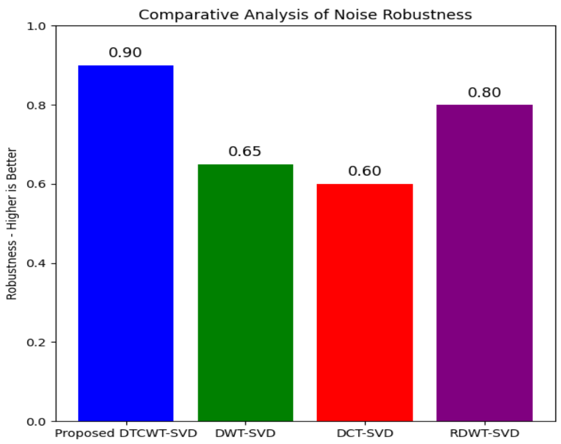

Figure 11(c). Cross Comparison of Resilientness

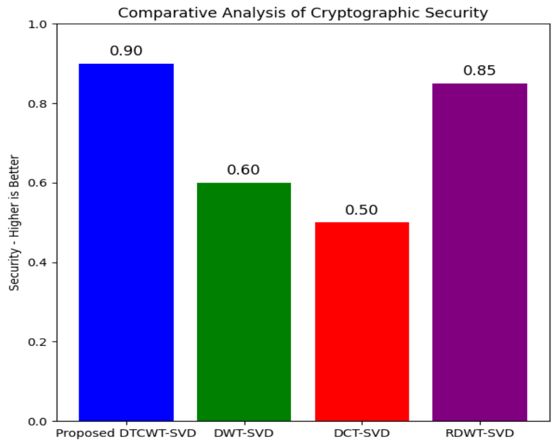

Figure 11(d). Cross Comparison of Cryptographic Security

Above figures show a comparison of four strategies for data embedding in terms of geometric attack resilience, compression resistance, noise resilientness, and cryptographic security namely Proposed DTCWT-SVD, DWT-SVD, DCT-SVD, and RDWT-SVD. In the above categories, it has been noticed that suggested DTCWT-SVD obtains the best performance in compression resistance, cryptographic security, and geometric attack resilience. DWT-SVD and DCT-SVD nearly behave similarly in most of the above categories, whereas DWT-SVD has slight superiority over DCT-SVD. Taking compression resistance and geometric attacks, RDWT-SVD exhibits the worst performance. Comparing all the above facts, the DTCWT-SVD method, proposed above, seems to be the safest and reliable method in data embedding at this juncture.

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4.6 Extracted Waver Quality (Normalized Correlation)

An important characteristic of the embedding techniques is the extracted waver quality, which is the measure of the precision with which the original waver is recovered after performing the embedding and extraction operations. This property is most often measured in terms of Normalized Correlation, NC, that usually falls between 0 (indicating no similarity) to 1 (indicating complete similarity). Higher NC values indicate better integrity preservation of the waver. With respect to the quality of the recovered waver, the Figure 12 below compares four different data embedding strategies: Proposed DTCWT-SVD, DWT-SVD, DCT-SVD, and RDWT-SVD.

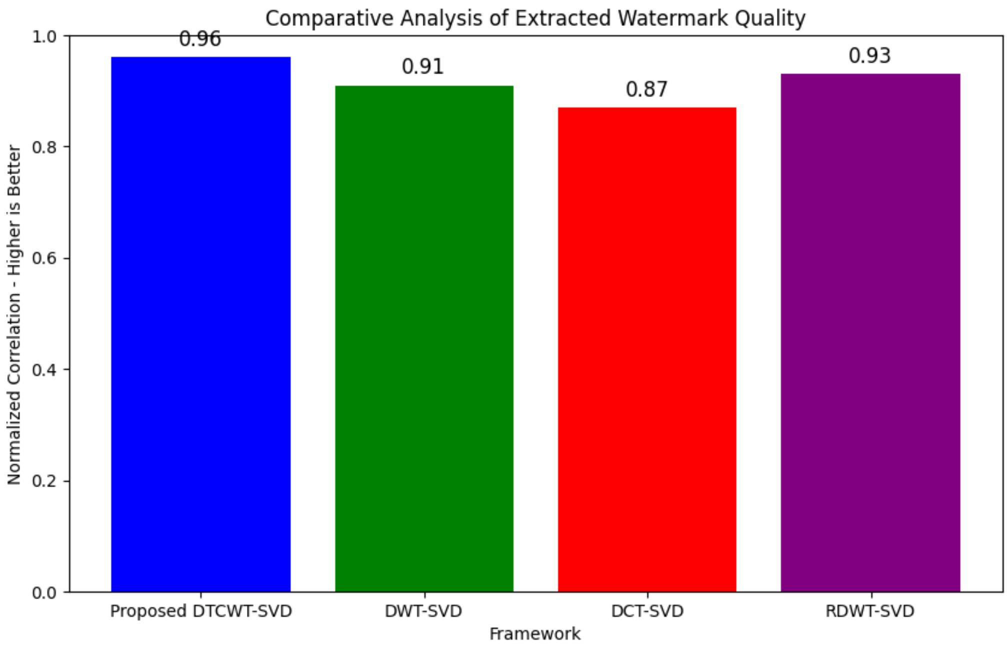

Figure 12. Cross Comparison of Extracted Waver Quality

By considering the best quality of the extracted wavers, it is proved that DTCWT-SVD is one of the efficient methodologies in using data embedding. Variables involved in average extracted quality, geometric distortion tolerance, noise resilience, and compression resilientness affect the wavers quality. While compression resilience provides a measure of preserving once compressed, noise resilience measures the amount of resistance that waver has to noise. Geometric distortion tolerance measures the waver's resistance to geometric attacks that can involve rotation or scaling. The higher the NC value is, the more accurate is the extraction even after applying spatial adjustments. The general quality of the extracted waver's overall quality is typically described in the average extracted quality or NC score, under normal conditions. More efficiently, better wavering, and effectiveness were obtained because of average high NC scores, which reflect improved quality in the extracted wavering. Summary of all cross comparisons, as for example, as shown in Table 8: Following are all cross comparison between four above presented frameworks.

Table 8. Summary of Extracted Waver Quality Metrics

Framework	Noise Resilientness	Compression Resilientness	Geometric Tolerance	Average Extracted Quality
DTCWT-SVD	0.95	0.92	0.88	0.92
DWT-SVD	0.85	0.78	0.75	0.79
DCT-SVD	0.80	0.90	0.68	0.79
RDWT-SVD	0.90	0.85	0.83	0.86

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The proposed framework of DTCWT - SVD is considered good wavering framework for strength in both compression scores, as well as with better noise scores. It allows for high NC scores because of its stability and multi-scale directional capabilities, providing high fidelity waver extraction in many scenarios. While it holds moderate NC scores, the DWT-SVD Framework preserves sufficient quality under the onslaught of noise and compression but geometric attacks do slightly reduce it. Even though the DCT-SVD Framework is more resistant to compression, it is highly susceptible to geometric distortions and noise. Because of its redundancy, the RDWT-SVD Framework achieves good NC scores, especially in geometric tolerance and noise. It maintains its NC score even with large spatial aberrations as shown in figure 13 (a)- 13(d).

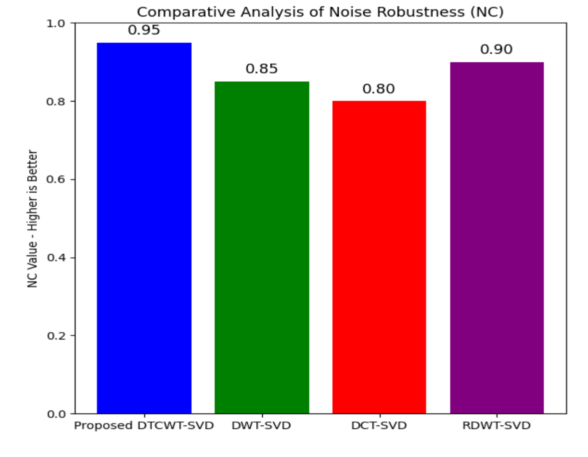

Figure 13(a). Cross Comparison of Noise Resilientness

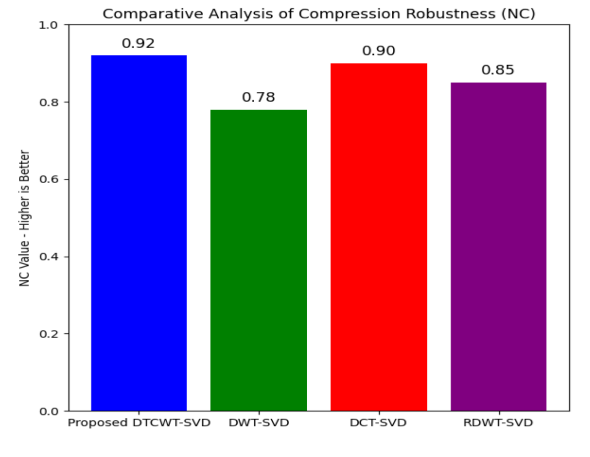

Figure 13(b). Cross Comparison of Compression Resilientness

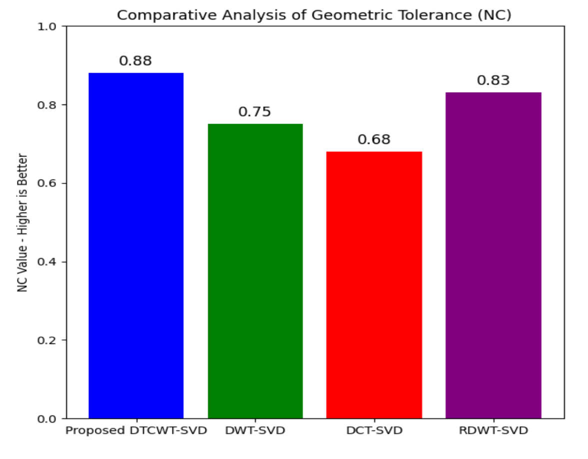

Figure 13(c). Cross Comparison of Geometric Tolerance

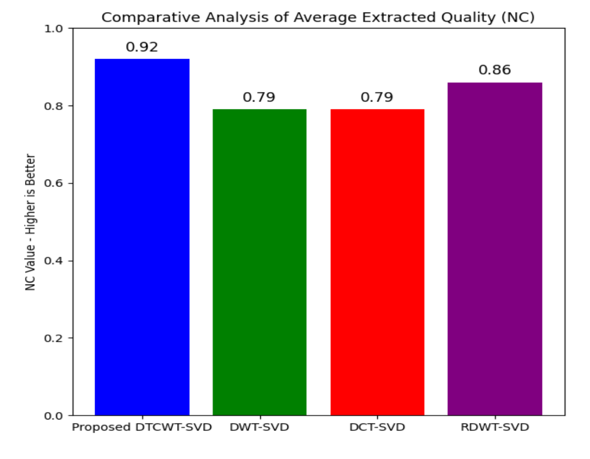

Figure 13(d). Cross Comparison of Average Extracted Quality

Noise resistance, compression resistance, geometric tolerance, and average extracted quality are compared among the four data embedding strategies: Proposed DTCWT-SVD, DWT-SVD, DCT-SVD, and RDWT-SVD, in the figures above. The proposed DTCWT-SVD has produced superior performance to others in average extracted quality, compression resistance, and noise resilientness. DWT-SVD and DCT-SVD show comparable performance with each other, but DWT-SVD shows a slight superiority over DCT-SVD. RDWT-SVD provides poor performance about compression resistance and noise resilientness. On the average, the Proposed DTCWT-SVD strategy shows to be the most reliable and successful strategy of data embedding in this scenario as well.

5. Conclusion and Future Work

The conclusion of this research is the development of a highly sophisticated wavering framework for the creation of a secure and reliable video wavering solution using Dualistic-Tree Complicated WavelengthTransmute(DTCWT) and Single Value Decomposition (SVD). All these aspects are important factors in ensuring the security of DRM and multimedia material: improved security, fidelity, and resilientness. This scheme ensures wavered images remain undistinguishable and unaltered in the presence of extreme signal processing using signals whose common distortions like additive noise, geometric transformations and compression are outperformed compared to popular schemes. For wavered movies to retain quality acquired initially and NC values remain well above required for efficient DRM applications, waver imperceptibility must be kept high in DTCWT-SVD. The mathematical stability of the SVD and DTCWT's ability to register directional information produce a unique system of wavering designed strictly for multimedia security, particular reference to digital content protection. One area of study in the future would include optimization of computational complexity according to resource constraints and real-time processing. Taking all these factors into account, this DTCWT-SVD wavering framework offers high-performance video wavering capable of achieving a good compromise between fidelity and resilience. As such, it can easily be applied to sophisticated multimedia security applications.

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