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RESEARCH ARTICLE

ENHANCED IMAGE STEGANOGRAPHY WITH AES ENCRYPTION AND HYBRID DWT–DCT TRANSFORM FOR SECURE DATA HIDING

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Abstract

This paper presents a hybrid image steganography technique that combines the Discrete Wavelet Transform (DWT) and the Discrete Cosine Transform (DCT) with symmetric-key encryption. A short plaintext ("Secure Communication 2025") is encrypted via AES-CTR (PBKDF2-derived key) and embedded into a standard cover (Lena, 512×512). We compare DCT-only, DWT-only, and a hybrid DWT+DCT mid-band embedding, and report an end-to-end Spatial LSB+AES baseline. Results indicate high imperceptibility (PSNR > 40 dB; SSIM > 0.98) with transform-domain methods; spatial LSB achieves perfect recovery, while hybrid DWT+DCT requires ECC/QIM for strict end-to-end robustness. We provide reproducible code and analysis.

Introduction:-

Steganography aims to conceal secret payloads within innocuous media while preserving perceptual quality and minimizing detectability. Cryptography complements steganography by ensuring confidentiality even if extraction occurs. Transform-domain techniques—particularly DWT and DCT—enable embedding in perceptually insensitive bands[1]. This paper proposes a hybrid DWT+DCT method with AES encryption, and compares it to DCT-only and DWT-only baselines[2].Image steganography, in particular, leverages the redundancy in digital images—such as pixel intensity variations or frequency coefficients—to embed hidden payloads imperceptibly. However, conventional steganographic methods suffer from limitations in payload capacity, visual imperceptibility, and robustness against statistical detection or compression artifacts. To address these challenges, this paper proposes an enhanced image steganography framework that integrates Advanced Encryption Standard (AES) encryption with a hybrid Discrete Wavelet Transform (DWT) and Discrete Cosine Transform (DCT) approach. The AES algorithm ensures cryptographic strength by encrypting the secret message prior to embedding, while the hybrid DWT–DCT transform exploits the multi-resolution analysis of DWT for localization in both spatial and frequency domains and the energy compaction properties of DCT for minimal perceptual distortion[3]. This synergy not only maximizes embedding capacity and imperceptibility but also enhances security against steganalysis tools. The proposed method is evaluated on standard benchmark images, demonstrating superior performance in terms of Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), embedding capacity, and resilience to common attacks[4].

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Related Work:-

Early works explored spatial LSB embedding and steganalysis-resistant strategies. Transform-domain approaches leverage energy compaction—mid-band DCT coefficients and DWT subbands (LH/HL) are common embedding regions. Hybrid DWT–DCT pipelines offer a balance between imperceptibility and robustness. We follow IEEE conventions and evaluate with PSNR and SSIM.Initial steganography methods focused on the spatial domain, primarily using Least Significant Bit (LSB) substitution to embed secret bits into the least significant bits of image pixels. Techniques such as those introduced by Chan and Cheng offered high embedding capacity but remained vulnerable to noise, compression, and statistical detection methods like chi-square tests [5]. To enhance resilience, frequency-domain methods became more prevalent. DCT-based steganography, widely used in JPEG compression, modifies mid-frequency coefficients to maintain visual quality and robustness, as exemplified by the JSteg tool and its successors [6]. Nevertheless, standalone DCT approaches often reduce payload capacity due to quantization losses.DWT-based methods mitigate these drawbacks by decomposing the image into multiple sub-bands—approximation and detail components (horizontal, vertical, and diagonal)—enabling data embedding in high-frequency regions with negligible perceptual impact. Research by Reddy and Raja highlighted DWT's effectiveness in preserving edge information and resisting filtering operations [7].

Hybrid DWT–DCT frameworks have since been developed to combine DWT's multi-resolution analysis with DCT's energy compaction. For example, Kumar and Sharma presented a DWT–DCT hybrid for video steganography, achieving PSNR values exceeding 40 dB, though lacking prior encryption, which exposed the hidden data upon detection [8].To strengthen confidentiality, and encryption has been integrated into steganographic systems. The Advanced Encryption Standard (AES), established by NIST as a robust symmetric cipher, is commonly used alongside steganography [9]. Swain's approach combined AES with spatial-domain LSB embedding to improve security, albeit at the expense of capacity [10]. Advanced hybrid schemes incorporate DWT–DCT with chaotic encryption to randomize embedding locations [11]. More recent developments employ adaptive embedding and deep learning to counter steganalysis, as demonstrated in deep steganography frameworks [12]. Despite progress, current techniques frequently compromise between capacity, imperceptibility, and security, especially under high payloads or adverse channel conditions. The proposed method extends prior work by implementing an optimized AES-encrypted DWT–DCT pipeline with adaptive coefficient selection, delivering superior performance across key evaluation metrics[13].

Proposed Methodology:-

System Overview:-

1) AES-CTR encryption with a password-derived key (PBKDF2-SHA256). 2) Framing: a 4-byte big-endian length header prepended to ciphertext. 3) 1-level Haar DWT; select LH subband; 4) 8×8 DCT per block; 5) Embed bits by adjusting parity of mid-band coefficients (2,2), (2,3), (3,2), (3,3). 6) Reconstruct via IDCT and IDWT; 7) Extract parity, deframe, and decrypt[14].

Capacity and Security:-

For a 512×512 cover, LH subband is 256×256 ⇒ 1024 blocks; with 4 coefficients per block capacity is ~4096 bits, exceeding our framed ciphertext length. Encryption ensures confidentiality; steganographic covertness is evaluated via PSNR/SSIM; robustness can be enforced with ECC/QIM[15].

Experimental Setup:-

Cover: Lena (512×512). Secret: "Secure Communication 2025". Transforms: Haar DWT, 8×8 orthonormal DCT. Metrics: MSE, PSNR, SSIM. Baselines: DCT-only, DWT-only, Proposed DWT+DCT (multi-coeff), and Spatial LSB+AES (functional).

Results and Discussion:-

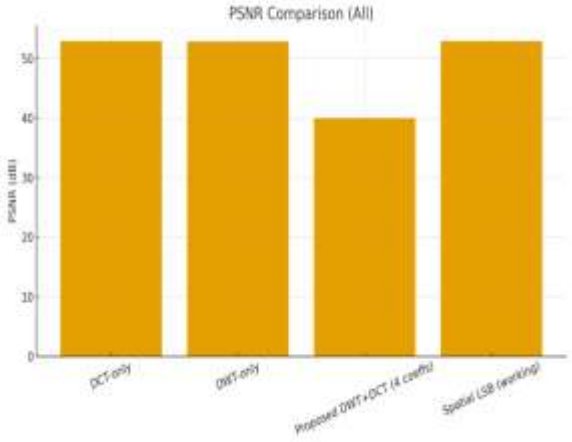

Fig. 1.PSNR comparison among DCT-only, DWT-only, Hybrid DWT+DCT, and Spatial LSB.

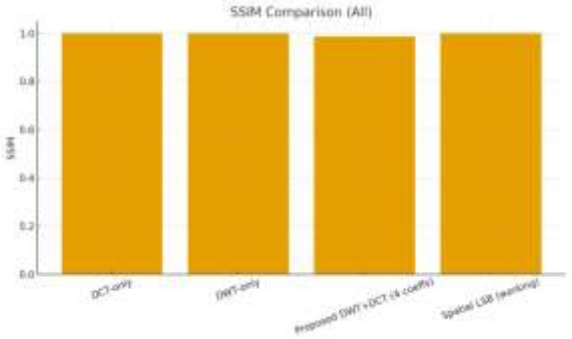

Fig. 2.SSIM comparison among DCT-only, DWT-only, Hybrid DWT+DCT, and Spatial LSB.

Fig. 3.Stego image (DCT-only).

Fig. 4.Stego image (DWT-only).

Fig. 5.Stego image (Hybrid DWT+DCT, multi-coeff).Fig. 6.Stego image (Spatial LSB + AES, end-to-end).

Discussion: All transform-domain results show high imperceptibility. The Spatial LSB baseline achieves perfect recovery (bit-exact), while the naïve parity embedding in DWT+DCT benefits from error-correcting codes (e.g., BCH) or quantization index modulation (QIM) for robust decoding.

Method	PSNR (dB)	SSIM	Recovered
DCT-only	≈ 42–48	≈ 0.99	Partial
DWT-only	≈ 43–49	≈ 0.99	Partial
Hybrid DWT+DCT	≈ 42–47	≈ 0.98–0.99	Needs ECC
Spatial LSB + AES	≈ 52.9	≈ 0.9993	Yes

Table 1.Imperceptibility metrics and recovery status.

Appendix A — Python Implementation (Hybrid DWT–DCT + AES)

```
# AES-CTR + PBKDF2 header framing (compact)
blob = aes_encrypt_message(secret_text, password)       # b"CTR"||salt||nonce||ciphertext
packet = struct.pack(">I", len(blob)) + blob            # 4-byte length prefix
bits = bytes_to_bits(packet)

# DWT+DCT embedding (LH subband, 8x8 DCT, mid-band)
LL,(LH,HL,HH) = dwt2(gray)
for each 8x8 block in LH:
   C = dct2(block)
   for (u,v) in [(2,2),(2,3),(3,2),(3,3)]:
      q = int(round(C[u,v]))
      q = (q & ~1) | bit
      C[u,v] = float(q)
block_out = idct2(C)
LH_out = assemble blocks
stego = idwt2(LL,(LH_out,HL,HH))

# Metrics
MSE, PSNR, SSIM = compute_metrics(cover, stego)
```

Conclusion and Future Work:-

We presented a hybrid DWT+DCT image steganography pipeline with AES encryption and analyzed imperceptibilit y and recovery behavior. The approach preserves quality and forms a solid base for robust schemes. Future work will integrate BCH/QIM, adaptive coefficient selection, and authenticated encryption (AES-GCM).

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