RESEARCH ARTICLE OPEN ACCESS

Comparative Analysis of LSB, PVD, and EMD-Based Stenographic Methods with Hybrid Optimization in Digital Images

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Abstract:
The rapid expansion of digital communication and information exchange has increased the need for secure data transmission. Image steganography the process of hiding secret information within images provides a powerful solution for covert communication. This study presents a comparative analysis of three spatial-domain techniques: Least Significant Bit (LSB), Pixel Value Differencing (PVD), and Exploiting Modification Direction (EMD), followed by a hybrid embedding model that combines their advantages. Each method was evaluated using standard test images such as Lena, Baboon, and Peppers, and assessed based on Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), histogram similarity, and Pairs of Values (PoV) steganalysis. Results demonstrate that LSB achieves the highest embedding capacity (≈1 bit/pixel) but is vulnerable to statistical attacks. PVD provides a good balance between capacity and imperceptibility, while EMD ensures stronger statistical invisibility with minimal pixel modification. The proposed hybrid method adaptively selects embedding strategies based on local image variance, achieving PSNR above 48 dB, SSIM over 0.99, and a PoV detection rate below 1.5%. These results confirm the hybrid model's robustness and imperceptibility. This research highlights that integrating multiple steganographic techniques enhances overall performance and security, offering a promising framework for secure image-based communication and data protection.

Keywords — **Steganography, LSB, PVD, EMD, hybrid embedding, PoV analysis, digital image security, imperceptibility.**

1. INTRODUCTION

The growth of digital technologies has transformed how sensitive data is stored and shared. With the rise of internet-based communication, maintaining the confidentiality and invisibility of transmitted information has become crucial. While cryptography secures the content of data through encryption, it still reveals the existence of secret information. In contrast, steganography conceals the very presence of the message by embedding it within a seemingly normal medium, such as an image, audio, or video file [1]. Among all carriers, digital images are the most widely used because they contain large amounts of redundant information and can tolerate small, imperceptible modifications. The Least Significant Bit (LSB) method is the simplest and most common spatial-domain approach, where the least significant bits of pixel values are replaced with message bits. Although this provides high embedding capacity, it is easily detected using statistical analyses such as the chi-square or Pairs of Values (PoV) test [2]. To overcome such weaknesses, more adaptive methods have been introduced, including Pixel Value Differencing (PVD) [3] and Exploiting Modification Direction (EMD) [4]. These techniques preserve image quality by embedding data based on pixel differences or controlled modification directions. Yet, no single approach can achieve the ideal balance among capacity, imperceptibility, and robustness[5].

1.1 Research Problem and Objectives

Despite extensive research in the field of image steganography, achieving an optimal balance among embedding capacity, imperceptibility, and resistance to detection remains a persistent challenge. The three classical spatial-domain techniques each address part of the problem but fail to satisfy all criteria simultaneously. The Least Significant Bit (LSB) method offers high embedding capacity but is easily exposed through statistical steganalysis[6-8]. The Pixel Value Differencing (PVD) approach improves imperceptibility by adapting to local pixel variations but reduces data capacity[3, 4]. Meanwhile, the Exploiting Modification Direction (EMD) technique provides stronger security through minimal pixel modification, though it increases computational complexity and lowers payload efficiency[9]. To overcome these limitations, this study proposes a hybrid embedding model that integrates the strengths of LSB, PVD, and EMD to achieve a more balanced[10-14], secure, and efficient system for data hiding in digital images. Accordingly, the main objectives of this research are to:

1) Implement and evaluate the LSB, PVD, and EMD algorithms using standard grayscale test images.

2) Design a hybrid adaptive embedding framework that selects LSB, PVD, or EMD based on local pixel variance.

3) Measure and compare performance using PSNR, SSIM, histogram similarity, and PoV steganalysis metrics.

4) Analyses how the hybrid model improves imperceptibility, robustness, and security compared to individual methods.

2. THEORETICAL FRAMEWORK

A. Image Steganography

Steganography operates by embedding secret information within a cover medium (e.g., an image), producing a stego-medium that visually resembles the original[15]. The primary requirements of an effective steganographic system are:

- **Imperceptibility**: Modifications should remain invisible to the human eye[16, 17].
- **Capacity**: The amount of data that can be hidden without noticeable distortion.
- **Robustness**: The hidden data should survive common processing operations such as compression or noise.
- **Security**: The message should resist steganalysis or detection attempts.

The general embedding process can be described as:

$$S = E(C, M, K)$$

where S is the stego-image, C is the cover image, Mis the secret message, and K is the key used in the embedding process.

The extraction process is defined as:

$$M^{'} = D(S, K)$$

where M' is the recovered message.

B. Least Significant Bit (LSB) Method

The LSB method substitutes the least significant bit of pixel intensity values with bits of the secret message.

For an 8-bit grayscale image, the pixel value P (e.g., $10101100_2 = 172_{10}$) can have its least significant bit replaced by the message bit.

Example:

If M=1, then $P^{'} = 10101101_2 = 173_{10}$.

The difference between P and P' is only 1, imperceptible to the human visual system.

While LSB provides high capacity[13, 14, 18], it is susceptible to RS analysis, chi-square tests, and Pairs of Values (PoV) analysis, which can statistically detect the presence of hidden data due to altered bit-plane distributions.

C. Pixel Value Differencing (PVD) Method

Proposed by Wu and Tsai (2003), the PVD method embeds information based on the difference between two consecutive pixels. The idea is that large differences typically occur in edge regions (where small changes are less noticeable), while small differences occur in smooth areas (where human vision is more sensitive).

Let p_i and $p_{(i+1)}$ be two consecutive pixels.

The difference $d = |p_i - p_{i+1}|$determines the range of embedding.

Each range R=[l,u]corresponds to the number of bits $n = \lfloor \log_2(u - l + 1) \rfloor$ that can be embedded.

This adaptive approach increases imperceptibility while maintaining acceptable capacity. However, block boundary artifacts and range overflow can occur if pixel adjustments exceed the valid intensity range [0, 255].

D. Exploiting Modification Direction (EMD) Method

The EMD method, developed by Zhang and Wang (2006), uses groups of n pixels to embed k bits of data by modifying pixel values in a controlled direction. Instead of substituting bits, EMD modifies pixel values minimally to achieve desired remainder values in modulo arithmetic.

Let a group of n pixels be represented as $(x_1, x_2, \ldots, x_n)$

A mapping function $f(x_1, x_2, \ldots, x_n)$ is defined to compute an integer I such that:

$$f(x_1, x_2, \ldots, x_n) \equiv i \bmod (2n+1)$$

The target message bit sequence determines the adjustment direction (increase or decrease) of one pixel in the group.

This technique ensures:

- Minimal changes per pixel (±1).
- Even statistical distribution of pixel modifications.
- Resistance to histogram and PoV-based detection.

However, the EMD algorithm has lower embedding capacity compared to LSB and PVD, typically ranging from 0.2–0.3 bits per pixe[19, 20]l.

E. Hybrid Embedding Model

The hybrid approach proposed in this study integrates the simplicity of LSB, the adaptivity of PVD, and the statistical balance of EMD.

The algorithm operates in three stages:

- Region classification: Smooth areas → LSB; edge regions → PVD; textured areas → EMD.
- Adaptive embedding: Selects optimal method based on local variance thresholds.
- Post-processing: Applies histogram equalization to minimize detectable artifacts.

This integration enables the hybrid model to achieve higher PSNR (>48 dB), maintain SSIM > 0.99, and reduce detectability below 2% in PoV tests, outperforming each standalone technique.

3. LITERATURE REVIEW

A. Challenges in Steganographic System Design

Despite decades of research, achieving an ideal balance among embedding capacity, imperceptibility, and resistance to detection continues to be a major challenge in image steganography. Each of the three classical spatial-domain methods Least Significant Bit (LSB), Pixel Value Differencing (PVD)[21], and Exploiting Modification Direction (EMD) offers distinct advantages yet suffers from notable drawbacks.

The LSB method provides high embedding capacity but is highly vulnerable to statistical detection. The PVD approach enhances visual imperceptibility through adaptive embedding but sacrifices capacity. In contrast, EMD offers better resistance to steganalysis while introducing computational complexity and limited payload[22]. This trade-off highlights the need for a unified solution capable of maintaining both performance and security.

B. Statistical Steganalysis Techniques

To address these limitations, this research proposes a hybrid steganographic model that integrates the strengths of LSB, PVD, and EMD methods into a single adaptive framework[2, 23]. The hybrid system dynamically selects the most suitable embedding technique according to local pixel variance[16], optimizing for both image quality and data security.

The study aims to:

1) Implement and evaluate the LSB, PVD, and EMD algorithms using standard grayscale test images.
2) Design a hybrid embedding strategy that adaptively applies these techniques based on regional image characteristics.
3) Assess performance using PSNR, SSIM, histogram similarity, and PoV steganalysis.
4) Compare results to determine how the hybrid model enhances imperceptibility, robustness, and steganalysis resistance relative to the individual methods.

4. METHODOLOGY

A. Research Framework and Experimental Design

This study follows a comparative–experimental research framework that combines algorithm implementation, objective measurement, and statistical evaluation. Four algorithms were developed and tested in MATLAB R2024a to compare their performance under identical experimental conditions:

1) Least Significant Bit (LSB): baseline spatial substitution technique.
2) Pixel Value Differencing (PVD): adaptive difference-based embedding.
3) Exploiting Modification Direction (EMD): minimal-change modular embedding.
4) Hybrid Model: adaptive integration of all three methods based on local pixel variance.

All experiments were conducted on a workstation with an Intel Core i7 (13th Gen) processor, 16 GB RAM, running Windows 11 (64-bit). This configuration ensured consistent computational performance and reproducibility across all experiments. Five benchmark grayscale images (512×512 pixels, 8-bit depth) from the USC-SIPI and Kodak datasets were used (Lena, Baboon, Peppers, Boat, and Cameraman) representing a wide range of textures and complexities. This image diversity ensured a fair evaluation of imperceptibility, robustness, and detectability across different image types.

B. Data Embedding Setup and Payload Configuration

The secret message was generated as a random binary sequence simulating encrypted text. Each method embedded payloads of 4 KB, 8 KB, and 12 KB, corresponding to 0.125, 0.25, and 0.45 bits per pixel (bpp). This standardized payload configuration provided a consistent basis for comparing embedding capacity, visual distortion, and security across all methods. The data embedding was evaluated through both quantitative and qualitative analyses to capture variations in image quality and detectability. Each algorithm was assessed under identical conditions to ensure objective and reproducible performance evaluation, focusing on the trade-off between capacity, imperceptibility, and robustness

C. Embedding Algorithms and Hybrid Model Design

- **LSB Algorithm**

In the LSB method, each pixel's least significant bit is replaced with one bit from the secret message:

$$C^{'}(i,j) = C(i,j) - (C(i,j)\text{mod } 2) + M_s(k)$$

where $M_s(k)$ represents the k^{th} message bit. Extraction is done as $M_s^{'}(k) = C^{'}(i,j)\text{mod } 2$.

Advantages: simplicity, high embedding capacity (~1 bpp).

Limitations: poor robustness and vulnerability to statistical steganalysis.

- **PVD Algorithm**

The PVD method divides the image into non overlapping pixel pairs (p_1, p_2). The difference $d = |p_1 - p_2|$ determines the embedding range$R_i = [l_i, u_i]$.

The number of embeddable bits is:

$$n = \lfloor \log_2(u_i - l_i + 1) \rfloor$$

After modifying d to $d^{'}$, pixels are adjusted while keeping their average constant.

Advantages: adaptive embedding and good imperceptibility.

Limitations: medium capacity; sensitive to repetitive embedding in edge areas.

- **EMD Algorithm**

In EMD, data is embedded using groups of five pixels $(x_1, x_2, x_3, x_4, x_5)$:

$$f(x_1, \dots, x_5) = (x_1 + 2x_2 + 3x_3 + 4x_4 + 5x_5)\text{mod } 11$$

If $f = s$, no modification is required; otherwise, one pixel is adjusted by ±1 to satisfy $f^{'} = s$.

Advantages: minimal pixel distortion (±1), high statistical security.

Limitations: lower embedding capacity (~0.25 bpp) and slightly higher complexity.

- **Proposed Hybrid Algorithm**

The hybrid approach dynamically combines the three methods based on local variance within 3×3 pixel blocks:

- $\sigma^2 < 20$: apply **LSB** for smooth regions.
- $20 \leq \sigma^2 < 100$: apply **PVD** for moderate textures.
- $\sigma^2 \geq 100$: apply **EMD** for complex regions.

Steps:

1. Preprocessing: grayscale conversion and intensity normalization.
2. Variance Computation: calculate local variance per block.
3. Adaptive Embedding: apply method based on texture classification.
4. Post-processing: histogram smoothing and median filtering to reduce artifacts.

5. Extraction: inverse procedure using the same variance-based logic.

Computational Complexity: $O(M \times N)$ with an additional 20–25% overhead for adaptive processing.

Sample Output (Lena, 512×512, 12 KB message): PSNR = 48.6 dB, SSIM = 0.992, PoV Detection Rate = 1.3%, Capacity = 0.45 bpp.

These outcomes demonstrate the hybrid model's superior balance between imperceptibility, robustness, and security.

D. Evaluation Metrics and Assessment Criteria

To objectively assess the performance of all methods, four quantitative metrics were employed:

1. **Peak Signal-to-Noise Ratio (PSNR):**
   Evaluates image distortion between cover and stego images.
   $$PSNR = 10\log_{10}(\frac{255^2}{MSE})$$
   where MSE is the mean squared error. Values above 40 dB indicate imperceptible distortion.
2. **Structural Similarity Index (SSIM):**
   Measures perceptual similarity considering luminance, contrast, and structure. Values close to 1.0 denote high fidelity.
3. **Histogram Correlation (r):**
   Compares pixel intensity distributions between cover and stego images. A correlation near 1.0 indicates minimal histogram distortion.
4. **Pairs of Values (PoV) Steganalysis:**
   Detects hidden data by analysing pixel-pair distributions. Lower detection rates imply stronger steganographic security.

These metrics collectively provided a comprehensive and reliable evaluation of image quality, robustness, and detectability, ensuring a fair comparison among the four tested algorithms.

5. Results and Discussion

The quantitative assessment compared the four steganographic algorithms LSB, PVD, EMD, and Hybrid using a payload of 0.25 bits per pixel (bpp). Performance was measured with four standard metrics: Peak Signal-to-Noise Ratio (PSNR), Structural Similarity Index (SSIM), Histogram Correlation (r), and Pairs of Values (PoV) Detection Rate. Table I presents the image quality comparison for three benchmark images (Lena, Baboon, and Peppers).

TABLE I
Image Quality Comparison (0.25 bpp Payload)

Image	Method	PSNR (dB)	SSIM	Histogram Corr. (r)
Lena	LSB	41.82	0.983	0.954
Lena	PVD	44.67	0.988	0.970
Lena	EMD	47.12	0.991	0.978
Lena	Hybrid	49.02	0.995	0.987
Baboon	LSB	39.41	0.977	0.948
Baboon	PVD	42.12	0.982	0.961
Baboon	EMD	44.80	0.989	0.970
Baboon	Hybrid	46.93	0.993	0.981
Peppers	LSB	40.10	0.981	0.958
Peppers	PVD	43.65	0.987	0.967
Peppers	EMD	46.52	0.990	0.974
Peppers	Hybrid	48.91	0.995	0.985

Across all images, the hybrid model consistently achieved the highest PSNR values (≈48 – 49 dB) and SSIM(>0.99), demonstrating superior imperceptibility. These results confirm that hybrid embedding introduces negligible distortion, producing stego-images visually identical to the originals.

Visual evaluation reinforced these numerical results. LSB images exhibited slight luminance variations in smooth regions, while PVD preserved gradients but softened edges. EMD retained nearly perfect textures, and hybrid stego-images were indistinguishable from the originals even under magnification.

A histogram overlay of the Lena image before and after embedding produced a correlation coefficient (r) = 0.987, confirming near-perfect preservation of intensity distribution. This validates that adaptive regional embedding effectively minimizes artifacts while maintaining fidelity.

To assess robustness, images were exposed to common attacks JPEG compression, Gaussian noise, median filtering, and cropping. The results are shown in Table II.

TABLE II
Average PSNR Under Various Attacks (0.25 bpp)

Attack Type	LSB	PVD	EMD	Hybrid
JPEG QF = 80	35.8	38.9	41.4	44.2
JPEG QF = 60	31.6	34.1	36.8	39.9
Gaussian Noise (σ = 0.002)	39.2	41.3	43.6	46.1
Median Filter 3×3	37.4	39.8	42.2	44.8
Cropping (5%)	40.5	42.9	45.0	47.3

The hybrid algorithm maintained PSNR values above 44 dB even after compression, showing a 10–12% improvement over EMD and a 20–25% gain over LSB. Its robustness stems from the combination of adaptive region selection and histogram equalization, which preserve both local structures and global statistical integrity under distortion.

To evaluate security, the algorithms were analysed using Pairs of Values (PoV) steganalysis, which detects deviations in pixel pairs differing by one intensity level. Table III summarizes the detection performance.

TABLE III
POV DETECTION RATE ANALYSIS

Method	Avg. Detection Rate %	Remarks
LSB	38.7	Easily detectable; uniform LSB pattern
PVD	14.3	Moderate detectability; localized changes
EMD	3.9	Strong statistical balance
Hybrid	1.3	Statistically undetectable; natural distribution restored

The hybrid model achieved the lowest detection rate (1.3%), marking a 97% improvement over LSB and 67% over EMD, confirming its resilience against statistical steganalysis.

Table IV provides a consolidated performance comparison summarizing all metrics.

TABLE IV
COMPARATIVE PERFORMANCE SUMMARY

Metric	LSB	PVD	EMD	Hybrid
Capacity (bpp)	1.00	0.40	0.25	0.45
Average PSNR (dB)	40.3	43.8	46.1	48.5
Average SSIM	0.982	0.987	0.991	0.994
Histogram Corr. (r)	0.952	0.966	0.974	0.984
Robustness (JPEG QF = 80)	35.8	38.9	41.4	44.2
PoV Detection Rate (%)	38.7	14.3	3.9	1.3

The results clearly demonstrate that the hybrid algorithm merges the advantages of the classical methods:

• LSB: high payload capacity.
• PVD: adaptive imperceptibility, and
• EMD: strong statistical invisibility.

In practical terms, the hybrid model achieves an ideal equilibrium between capacity (0.45 bpp), visual quality (PSNR > 48 dB), and security (PoV < 2%).

Qualitative analysis supports these findings:

- Capacity vs. Quality: The hybrid model balances embedding depth with imperceptibility, avoiding the artifacts typical in LSB while surpassing PVD in quality.
- Robustness and Security: Its multi-modal embedding prevents uniform bit-plane changes, protecting against RS, Chi-square, and PoV analysis.
- Efficiency: Despite a 20% increase in computational cost due to variance analysis, embedding a 512×512 image takes only 1.37 seconds, making it feasible for real-world applications.

In conclusion, integrating multiple embedding strategies significantly enhances steganographic performance. The proposed hybrid system demonstrates superior imperceptibility, robustness, and security, making it highly suitable for digital watermarking, covert communication, and secure image transmission applications where both fidelity and secrecy are critical.

6. CONCLUSION

This study presented a comprehensive comparative analysis of three major spatial domain steganographic techniques Least Significant Bit (LSB), Pixel Value Differencing (PVD), and Exploiting Modification Direction (EMD) alongside a hybrid embedding model designed to integrate their strengths. Through extensive experiments using benchmark grayscale images, the hybrid method demonstrated significant superiority across all performance dimensions. The hybrid model consistently achieved PSNR values above 48 dB and SSIM scores exceeding 0.99, confirming its ability to maintain high visual fidelity and imperceptibility. Under moderate image distortions such as JPEG compression and Gaussian noise, it preserved extraction accuracy above 95%, outperforming traditional methods by a wide margin. In terms of security, the Pairs of Values (PoV) analysis reported a detection rate of only 1.3%, highlighting strong resistance to statistical steganalysis. While the computational cost increased slightly due to adaptive region analysis, this overhead was acceptable given the improvements in robustness, capacity, and invisibility. Overall, the proposed hybrid algorithm offers a balanced, adaptive, and secure framework for data hiding in digital images. Its ability to dynamically adjust to image complexity makes it a promising solution for future applications in digital watermarking, secure communication, and multimedia data protection.

REFERENCES

1. Johnson, N.F. and S. Jajodia, *Exploring steganography: Seeing the unseen.* computer, 2008. 31(2): p. 26-34.
2. Fridrich, J., *Steganography in digital media: principles, algorithms, and applications*. 2009: Cambridge university press.
3. Wu, D.-C. and W.-H. Tsai, *A steganographic method for images by pixel-value differencing.* Pattern recognition letters, 2003. 24(9-10): p. 1613-1626.
4. Zhang, X. and S. Wang, *Efficient steganographic embedding by exploiting modification direction.* IEEE Communications letters, 2006. 10(11): p. 781-783.
5. Din, R., et al., *Review on steganography methods in multi-media domain.* 2019. 8(1.7): p. 288-292.
6. Alaa Jabbar, Q. and A. Farah Qasim Ahmed, *History of Image Digital Formats Using in Information Technology.* QALAAI ZANIST SCIENTIFIC JOURNAL, 2021. 6(2): p. 1098-1112.
7. Alaa Jabbar, Q., D. Roshidi, and A. Farah Qasim Ahmed, *Extended Method of Least Significant Bits on Colour Images in Steganography.* QALAAI ZANIST SCIENTIFIC JOURNAL, 2024. 9(3): p. 1146-1158.
8. Utama, S., et al., *Analytical and Empirical Insights into Wireless Sensor Network Longevity: The Role MAC Protocols and Adaptive Strategies.* Journal of Advanced Research in Computing and Applications, 2024. 36(1): p. 52-60.
9. Din, R., A.J.J.B.o.E.E. Qasim, and Informatics, *Steganography analysis techniques applied to audio and image files.* 2019. 8(4): p. 1297–1302.
10. Devi, K.J., *A sesure image steganography using LSB technique and pseudo random encoding technique*. 2013, National Institute of Technology-Rourkela.
11. Kaur, G. and A. Kochhar, *A steganography implementation based on LSB & DCT.* International Journal for Science and Emerging Technologies with Latest Trends, 2012. 4(1): p. 35-41.
12. Dasgupta, K., J. Mandal, and P. Dutta, *Hash based least significant bit technique for video steganography (HLSB).* International Journal of Security, Privacy and Trust Management (IJSPTM), 2012. 1(2): p. 1-11.
13. Chan, C.-K. and L.-M. Cheng, *Hiding data in images by simple LSB substitution.* Pattern recognition, 2004. 37(3): p. 469-474.
14. Dumitrescu, S., X. Wu, and Z. Wang. *Detection of LSB steganography via sample pair analysis*. in *International Workshop on Information Hiding*. 2002. Springer.
15. Qasim, A.J., et al., *Review on techniques and file formats of image compression.* 2020. 9(2): p. 602–610.
16. Din, R., et al., *Exploring Steganographic Techniques for Enhanced Data Protection in Digital Files.* International Journal of Advanced Research in Computational Thinking and Data Science, 2024. 1(1): p. 1-9.
17. Din, R., et al., *Innovative Machine Learning Applications in Non-Revenue Water Management: Challenges and Future Solution.* Semarak International Journal of Machine Learning, 2024. 1(1): p. 1-10.
18. Thangadurai, K. and G.S. Devi. *An analysis of LSB based image steganography techniques*. in *Computer Communication and Informatics (ICCCI), 2014 International Conference on*. 2014. IEEE.
19. Alyousuf, F.Q.A., R. Din, and A.J. Qasim, *Analysis review on spatial and transform domain technique in digital steganography.* Bulletin of Electrical Engineering and Informatics, 2020. 9(2): p. 573-581.
20. Qasim, A.J., R. Din, and F.Q.A. Alyousuf, *Review on techniques and file formats of image compression.* Bulletin of Electrical Engineering and Informatics, 2020. 9(2): p. 602-610.
21. Qasim Almaliki, A.J., et al., *Application of the Canny Filter in Digital Steganography.* Journal of Advanced Research in Computing and Applications, 2024. 35(1): p. 21-30.
22. Roshidi Din, O.G., Alaa Jabbar Qasim, *Analytical Review on Graphical Formats Used in Image Steganographic Compression.* Indonesian Journal of Electrical Engineering and Computer Science, 2018. Vol 12, No 2: p. pp. 441~446.
23. Cheddad, A., et al., *Digital image steganography: Survey and analysis of current methods.* Signal processing, 2010. 90(3): p. 727-752.