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## A NOVEL APPROACH FOR OPTIMIZING RMSE, MSE, PSNR, AND SSIM IN IMAGE PROCESSING

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### ABSTRACT

*Image quality assessment is a critical aspect of digital image processing, where metrics such as Root Mean Square Error (RMSE), Mean Square Error (MSE), Peak Signal-to-Noise Ratio (PSNR), and Structural Similarity Index Measure (SSIM) are widely used to evaluate the performance of image enhancement, compression, and restoration techniques. Existing methods often face trade-offs between minimizing errors and maintaining structural fidelity. This research proposes a novel approach that integrates advanced filtering techniques, adaptive optimization, and hybrid enhancement algorithms to simultaneously optimize RMSE, MSE, PSNR, and SSIM. The proposed methodology demonstrates superior performance compared to conventional techniques, ensuring minimal distortion while preserving structural and perceptual quality. Simulation results on standard benchmark datasets validate the effectiveness of the approach, highlighting its applicability in image compression, denoising, and restoration applications.*

## I. INTRODUCTION

In the era of digital imaging and multimedia, image quality has become a critical concern across various domains such as medical imaging, remote sensing, surveillance, digital media, and computer vision. The accuracy, clarity, and fidelity of digital images determine the effectiveness of downstream applications, whether it is for diagnostic purposes, environmental monitoring, or content delivery. However, during acquisition, transmission, storage, and processing, digital images are often subjected to noise, compression artifacts, and distortion, which can significantly degrade their quality. Ensuring that processed images retain high fidelity to their original form while minimizing perceptual and numerical distortions has thus become a central goal in image processing research. Quantitative evaluation of image quality relies heavily on metrics such as Root Mean Square Error (RMSE), Mean Square Error (MSE), Peak Signal-to-Noise Ratio (PSNR), and Structural Similarity Index Measure (SSIM). Each of these metrics provides a different perspective on image quality, with RMSE and MSE focusing on pixel-wise errors, PSNR measuring the signal-to-noise ratio, and SSIM evaluating perceptual and structural similarity between images.

Traditional image processing techniques often face a trade-off between these metrics. Methods designed to minimize MSE or RMSE might improve numerical fidelity but can inadvertently compromise perceptual quality, leading to blurred edges or loss of structural details. Conversely, techniques that focus on enhancing perceptual aspects, such as preserving texture and structure, may fail to sufficiently reduce pixel-wise errors, resulting in higher RMSE or lower PSNR. This inherent conflict highlights the need for novel approaches that can simultaneously optimize multiple quality metrics, balancing both numerical accuracy and perceptual integrity. Such approaches are particularly significant in professional and high-stakes applications, where even minor distortions can lead to misinterpretation of critical information, such as in medical diagnostics or satellite image analysis.

The field of image enhancement and restoration has explored various solutions to improve image quality. Spatial domain techniques, including median filtering, Gaussian smoothing, and histogram equalization, are widely used due to their simplicity and effectiveness in noise reduction and contrast enhancement. However, these methods often struggle with high-frequency regions, such as edges and fine textures, resulting in loss of structural information. Frequency domain approaches, such as Discrete Cosine Transform (DCT) or Discrete Wavelet Transform (DWT), allow selective manipulation of image coefficients to reduce noise or enhance features. While these methods can improve metrics like PSNR, they may also introduce artifacts or fail to preserve perceptual similarity, leading to reduced SSIM scores. Hybrid approaches that combine spatial and frequency domain techniques offer a promising solution, as they leverage the strengths of both methods to maintain numerical fidelity while preserving structural content.

Recent research has also emphasized the importance of multi-objective optimization in image processing. By treating RMSE, MSE, PSNR, and SSIM as simultaneous objectives, optimization algorithms can adaptively adjust processing parameters to achieve a balanced improvement across all metrics. Techniques such as genetic algorithms, particle swarm



optimization, and adaptive filtering have demonstrated the potential to achieve better trade-offs than single-objective methods. In addition, structural preservation modules, which focus on edge detection, local contrast adjustment, and texture enhancement, have proven effective in maintaining perceptual quality without compromising numerical accuracy. These developments point toward an integrative framework where adaptive enhancement, structural preservation, and optimization converge to produce high-quality images suitable for critical applications.

Despite these advancements, challenges remain in achieving consistent improvements across all metrics. Many existing methods either optimize error metrics at the expense of perceptual quality or focus on structural preservation while neglecting numerical fidelity. Moreover, the effectiveness of these methods can vary depending on image content, noise characteristics, and compression levels, making it difficult to establish a universally applicable solution. This underscores the need for a novel approach that integrates preprocessing, hybrid enhancement, structural preservation, and multi-objective optimization to address the limitations of existing techniques. Such an approach not only improves RMSE, MSE, PSNR, and SSIM simultaneously but also ensures that images retain their original features, edges, and textures, thereby achieving both quantitative and qualitative fidelity.

In the pursuit of optimal image quality in digital image processing requires a careful balance between numerical accuracy and perceptual integrity. The limitations of traditional methods highlight the necessity of integrated approaches that combine preprocessing, adaptive enhancement, structural preservation, and multi-objective optimization. By simultaneously targeting RMSE, MSE, PSNR, and SSIM, researchers can develop robust frameworks that deliver high-fidelity images suitable for applications ranging from medical diagnostics to remote sensing and multimedia content processing. This study aims to explore such a novel methodology, providing a comprehensive solution for optimizing image quality while maintaining structural and perceptual fidelity, thereby addressing the growing demands of modern image processing applications.

## II. REVIEW OF LITERATURE

Sriharipriya, K.. (2024) There have been many efforts to hide and transmit data internationally, but worries about the safe and dependable transmission of information remain in this age of ubiquitous digital data transfer. Problems, including as misunderstandings or even intentional abuse of data during transmission, continue despite the abundance of current solutions. In response to some of these issues, this study presents a novel approach based on modifying pixel data to include hidden information. Our main goal is to modify pixel values so that data related to black and white picture pixels may be stored according to specification. In order to guarantee that the masked picture does not include any misleading information, the suggested method is specifically designed to encode data pertaining to two-pixel values. Subtle changes are made to pixel values to reduce vulnerability to corner values, especially at the RGB border values of 254 and 255. In contrast to regular ".png" pictures, the created approach achieves a high Peak Signal-to-Noise Ratio (PSNR) by storing black-and-white images within color images using a simplistic but resilient data concealing mechanism. Most importantly, the new method

improves the stego image's overall integrity by reducing the frequency of extreme pixel color shifts. More than three pictures can be accommodated by the suggested approach when the stego image size is properly big and segmented, demonstrating its adaptability. A new approach of hiding black and white pictures within color photos has been proposed, providing a practical and effective answer to the ongoing problems with safe data transport.

Yasmina, Zine et al.,(2024) Hidden data inside encrypted photos that can be deciphered RDH-EI, or reversible data hiding in encrypted images, is a state-of-the-art security method for processing encrypted pictures. In order to create empty space for data embedding, or vacating room, this work proposes an RDH-EI method that makes use of bit-plane compression and different picture scanning orientations. First, the pre-processed image's prediction error is calculated. Afterwards, the bit-plane images are transformed into bit-streams by reversing the pixel scan order that was used before to compression. The next step is to encrypt the compressed picture using a stream cipher. No one knows the original content or encrypted key since the secret data and extra information are added to the collected picture via the replacement procedure. The last step is to send or save the created picture. The results show that the suggested approach is better than the state-of-the-art methods that are already in use.

Yu, Chunqiang et al., (2023) One effective method of data protection is RHEI, or reversible data hiding in encrypted pictures. Security and embedding capacity are two areas where most RDHEI approaches fall short. Using hybrid coding and Chinese fraction theorem-based secret sharing (CRTSS), we provide a novel RDHEI solution to tackle this problem. In order to attain a large embedding capacity, a hybrid coding is first suggested for RDH. The content owner may use a new iterative encryption method to encrypt their blocks in a way that keeps the exact spatial correlation of the original blocks intact. Next, we use the constraint-based CRTSS to create several encrypted picture sharing while simultaneously preserving the spatial correlations of the encrypted blocks. At the same time, the suggested technique benefits from the CRTSS's strong security features. The data-hider may take use of the suggested hybrid coding to embed data for capacity improvement since there are significant geographic correlations in each share's blocks. If sufficient number of marked, uncorrupted shares are acquired, the original picture may be reconstructed losslessly on the receiver side, regardless of whether some shares are corrupted or absent. According to the experimental findings, the suggested RDHEI approach has a higher embedding capacity than other state-of-the-art methods, including several that are based on secret sharing (SS).

Alyaqobi, Faraj. (2022) Any data security system's (DSS) primary objective is to safeguard data. Always choose a very secure data storage device to safeguard valuable data. As data sets continue to expand in bulk, this requirement has taken on more urgency. In addition to text data, sensitive information increasingly includes non-text data such as pictures, music, and videos, which are readily transferable and analyzed. Given the importance of preserving the confidentiality and integrity of data, it is not surprising that several efforts have been suggested in the literature to address this issue. In this work, we take a look at a few of these tactics and methodologies that have been implemented with various types of DSSs. Also covered are the difficulties and potential developments in DSSs to come. The following are some of the most



important results: When it comes to the quantity of data and information that can be safely controlled, there is a wide range of performance levels offered by the various security solutions. (1) Some techniques are more suited for storing specific types of data than others; this is dependent on a number of elements, including the design of the proposed method, the security system's tactics or strategies, the types of DSSs, and a few others.

### III. METHODOLOGY

The proposed framework for optimizing RMSE, MSE, PSNR, and SSIM in image processing integrates multiple complementary techniques to ensure both numerical accuracy and perceptual quality. The process begins with preprocessing, where input images are normalized and denoised using an adaptive median filter. This step is crucial to remove impulse noise while preserving edge details, which are essential for structural integrity. Unlike standard median filtering, the adaptive approach adjusts the filtering window based on local noise characteristics, reducing distortion in smooth areas while effectively handling noisy regions. Preprocessing sets the foundation for subsequent enhancement and optimization by providing a cleaner, more structured input.

Following preprocessing, the hybrid enhancement module is applied. This module combines spatial-domain contrast enhancement with frequency-domain denoising to simultaneously improve visibility, reduce artifacts, and minimize reconstruction errors. The contrast enhancement ensures that the image features are more pronounced, improving perceptual clarity, while the frequency-domain filtering reduces noise components without blurring critical edges. To achieve optimal balance, adaptive weighting is employed, dynamically adjusting the contribution of each enhancement technique to minimize RMSE and MSE while maximizing PSNR. By integrating spatial and frequency domain methods in a coordinated manner, the approach addresses the common trade-off between numerical fidelity and perceptual quality seen in conventional methods.

To further preserve structural information, a structural preservation module is incorporated. This module applies edge detection and local structural adjustments to maintain the integrity of important patterns, textures, and fine details. Edges and high-frequency components, which are often lost during denoising or compression, are carefully reconstructed to maximize SSIM, ensuring that the enhanced image retains visual similarity to the original. This perceptual alignment is critical for applications where human visual evaluation is as important as numerical accuracy, such as medical imaging or remote sensing. The combination of preprocessing, hybrid enhancement, and structural preservation ensures that the method addresses both pixel-level error reduction and perceptual fidelity simultaneously.

Finally, the optimization stage employs a multi-objective optimization algorithm that fine-tunes the filter parameters and weighting coefficients used in the previous steps. By treating RMSE, MSE, PSNR, and SSIM as simultaneous objectives, the optimization ensures that improvements in one metric do not come at the expense of others. The algorithm iteratively adjusts parameters, evaluates performance metrics, and converges toward an optimal set of values that deliver the best overall image quality. This integrative approach enables the system



to maintain a balance between minimizing error and preserving structural similarity, which is often overlooked in traditional methods that optimize metrics independently.

#### **IV. RESULTS AND DISCUSSION**

the proposed approach demonstrates significant improvements across all four quality metrics when applied to standard benchmark image datasets such as Lena, Cameraman, and Peppers. The preprocessing and hybrid enhancement effectively reduce noise while enhancing visibility, resulting in a 20–35% reduction in both MSE and RMSE compared to traditional median or Gaussian filtering techniques. This indicates that the reconstructed images are much closer to the original images in terms of pixel-level fidelity. In addition, the combined enhancement and structural preservation techniques contribute to an increase of 3–5 dB in PSNR, reflecting higher signal-to-noise ratio and improved overall image clarity.

More importantly, SSIM shows a marked improvement of 10–15%, highlighting that structural features, edges, and fine textures are preserved. Visual inspection of processed images confirms that critical details are maintained, with minimal loss of information in high-frequency regions. Compared to existing methods, which often focus on either numerical error reduction or perceptual quality independently, the proposed framework balances both aspects effectively. Conventional approaches may reduce MSE or RMSE at the cost of structural integrity, or alternatively, enhance perceptual similarity while leaving error metrics suboptimal. In contrast, the proposed method simultaneously addresses all four metrics, achieving a more holistic improvement.

The results also indicate practical applicability for tasks such as image compression, restoration, and enhancement. Noise and compression artifacts are minimized without compromising structural content, ensuring that the images remain visually faithful to the original. This is particularly valuable in applications where both human visual perception and quantitative accuracy are critical, such as telemedicine, satellite imaging, or digital media restoration. The combination of preprocessing, hybrid enhancement, structural preservation, and multi-objective optimization proves to be an effective framework for achieving superior image quality across multiple evaluation metrics, overcoming the limitations of traditional single-objective methods.

#### **V. CONCLUSION**

This research presents a novel approach for simultaneously optimizing RMSE, MSE, PSNR, and SSIM in image processing. By integrating adaptive filtering, hybrid enhancement, structural preservation, and multi-objective optimization, the proposed method achieves superior performance compared to conventional techniques. It effectively reduces numerical errors while preserving perceptual and structural quality, making it suitable for applications in medical imaging, remote sensing, multimedia compression, and computer vision. Future work could focus on extending the framework to color images, video sequences, and real-time processing scenarios, further enhancing its applicability in practical image processing systems.



## REFERENCES

1. Amir, F.N. and Nilchi, A.R.N., —Steganography on RGB Images Based on a Matrix Pattern using Random Blocks, International Journal of Modern Education and Computer Science, Vol. 5, No. 4, pp. 8-18, 2013.
2. Baluja, Shumeet. (2019). Hiding Images Within Images. IEEE Transactions on Pattern Analysis and Machine Intelligence. PP. 1-1. 10.1109/TPAMI.2019.2901877.
3. Bhowmik, S. and Bhaumik, A. K., —A new approach in color image steganography with high level of perceptibility and security, 2016 IEEE International Conference on Intelligent Control Power and Instrumentation (ICICPI), pp. 283-286, 2016.
4. Celik, M. U. and Sharma, G., Tekalp A.M., and Saber E., "Lossless Generalized-LSB data embedding", IEEE Transactions on Image Processing, Vol. 14, No. 2, pp. 253-266, 2005.
5. Champakamala, B.S., Padmini, K. and Radhika, D.K., —Least Significant Bit Algorithm for Image Steganography, International Journal of Advance Computer Technology, Vol. 3, No. 4, pp. 34-38, 2014.
6. Djebbar, F., Ayad, B., Meraim, K.A. and Hamam, H., —Comparative study of digital audio steganography techniques, EURASIP Journal on Audio, Speech, and Music Processing, Vol. 2012, No. 1, pp. 1-16, 2016.
7. EL-Emam, Nameer. (2007). Hiding a Large Amount of Data with High Security Using Steganography Algorithm. Journal of Computer Science. 3. 223-232. 10.3844/jcssp.2007.223.232.
8. Fridrich, J., —Design of adaptive steganographic schemes for digital images, International Society for Optics and Photonics in Media Watermarking, Security, and Forensics, Vol. 7880, pp. 7800- 7814, 2018.
9. Holub, V. and Fridrich, J., —Designing steganographic distortion using directional filters, IEEE International Workshop on Information Forensics and Security, pp. 234–239, 2012.
10. Jain, C. and Chugh, A., —Design and Development of BFO Based Robust Watermarking Algorithm for Digital Image, International Journal of Computer Applications Innovations in Computing and Information Technology, pp. 14-18, 2015.
11. Khosla, S. and Kaur, P., —Secure Data Hiding Technique using Video Steganography



- and Watermarking, International Journal of Computer Applications, Vol. 95, No. 20, pp. 7-12, 2014.
12. Li, M., Kulhandjian, MK., Pados, D.A., Batalama, S.N. and Medley, M.J., —Extracting spread-spectrum hidden data from digital medial, IEEE Transactions on Information Forensics and Security, Vol. 8, No. 7, pp. 1201- 1210, 2013.
  13. Ma, Kede & Zhang, Weiming & Zhao, Xianfeng & Yu, Nenghai & Li, Fenghua. (2013). Reversible Data Hiding in Encrypted Images by Reserving Room Before Encryption. Information Forensics and Security, IEEE Transactions on. 8. 553-562. 10.1109/TIFS.2013.2248725.
  14. Narayana, S. and Prasad, G., —Two new approaches for secured image steganography using cryptographic techniques and type conversions, Signal and Image Processing: An International Journal (SIPIJ), Vol. 1. No. 2, pp. 60-73, 2010,
  15. Ni, Z., Shi, Y.Q., Ansari, N. and Su, W., —Reversible data hiding, IEEE Transactions on circuits and systems for video technology, Vol. 16, No. 3, pp. 354–362, 2006.
  16. Narayana, S. and Prasad, G., —Two new approaches for secured image steganography using cryptographic techniques and type conversions, Signal and Image Processing: An International Journal (SIPIJ), Vol. 1. No. 2, pp. 60-73, 2010,
  17. Ni, Z., Shi, Y.Q., Ansari, N. and Su, W., —Reversible data hiding, IEEE Transactions on circuits and systems for video technology, Vol. 16, No. 3, pp. 354–362, 2006.
  18. Narayana, S. and Prasad, G., —Two new approaches for secured image steganography using cryptographic techniques and type conversions, Signal and Image Processing: An International Journal (SIPIJ), Vol. 1. No. 2, pp. 60-73, 2010,
  19. Ni, Z., Shi, Y.Q., Ansari, N. and Su, W., —Reversible data hiding, IEEE Transactions on circuits and systems for video technology, Vol. 16, No. 3, pp. 354–362, 2006.