

Comprehensive Review of Image Compression Techniques in Digital Image Processing

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Abstract: Digital Image Processing (DIP) has become an essential technology in modern communication, healthcare, multimedia systems, remote sensing, surveillance, and scientific research. The rapid growth of high-resolution image data has increased the demand for efficient image storage and transmission methods. Image compression techniques play a major role in reducing image size by eliminating redundant information while maintaining acceptable image quality. This review paper presents a comprehensive study of different image compression methods used in digital image processing. The paper discusses both lossless and lossy compression techniques, including JPEG, PNG, Huffman Coding, Run Length Encoding (RLE), Discrete Cosine Transform (DCT), Discrete Wavelet Transform (DWT), Singular Value Decomposition (SVD), fractal compression, and modern deep learning-based approaches. A comparative analysis of compression ratio and image quality is also presented. Furthermore, recent developments in artificial intelligence and hybrid compression models are reviewed to understand future trends in image compression systems.

Keywords: Digital Image Processing, Image Compression, Lossless Compression, Lossy Compression, DCT, DWT, JPEG, JPEG2000, Deep Learning.

I. INTRODUCTION

In today's rapidly advancing digital world, images have become a powerful medium for communication, analysis, and decision-making. With the widespread use of smartphones, high-resolution cameras, medical imaging systems, satellites, and surveillance technologies, an enormous volume of image data is being generated every second. Managing such large datasets requires efficient techniques for storage, transmission, and processing. Digital Image Processing (DIP) is a specialized field that focuses on applying computational techniques to enhance, analyze, and manipulate digital images. Among the various components of DIP, Image Compression plays a crucial role. Image Compression is the process of reducing the file size of an image by eliminating redundant or unnecessary information while maintaining an acceptable or original level of quality.

In the digital era, the need for efficient image storage and transmission has increased significantly due to the exponential growth of image-based content. The key challenge is to reduce the amount of data required to represent an image without sacrificing its perceptual quality. Image compression techniques are designed to achieve this balance, enabling both storage optimization and faster transmission. Image compression can be categorized into two broad types: lossless compression and lossy compression. Lossless techniques preserve all the original image data, while lossy methods allow some data loss to achieve higher compression ratios. This paper provides a comprehensive review of various image compression algorithms, their efficiency, and the trade-offs involved. Table 1 shows Overview of digital image processing in image compression technique

Table 1. Summary of Digital image processing in image compression technique

Sr. No	Technique	Compression Type	Working Principle	Advantages	Applications
1	JPEG (DCT-Based)	Lossy	Uses Discrete Cosine Transform (DCT) to remove less important image frequencies	High compression ratio, widely supported	Digital photography, web images
2	PNG Compression	Lossless	Uses predictive coding and Run Length Encoding (RLE)	Preserves original image quality	Scientific imaging, graphics, medical images

3	Huffman Coding	Lossless	Assigns shorter binary codes to frequent data values	Efficient entropy coding	Text and image compression
4	Run Length Encoding (RLE)	Lossless	Stores repeated pixel values as single data values	Simple and fast compression	Fax systems, bitmap images
5	JPEG 2000	Lossy/Lossless	Uses Discrete Wavelet Transform (DWT)	Better quality at high compression ratios	Medical imaging, satellite imaging
6	Discrete Cosine Transform (DCT)	Lossy	Converts image data into frequency components	Reduces redundancy effectively	JPEG compression systems
7	Discrete Wavelet Transform (DWT)	Lossy	Decomposes image into multi-resolution wavelet coefficients	High image quality and scalability	MRI, CT scan, multimedia
8	Fractal Compression	Lossy	Uses self-similarity patterns within images	High compression efficiency	Medical and natural images
9	Predictive Coding	Lossless	Predicts pixel values from neighboring pixels	Reduces spatial redundancy	PNG and medical imaging
10	SVD-Based Compression	Lossy	Uses Singular Value Decomposition to reduce data dimensions	Good reconstruction quality	Scientific and research imaging
11	Hybrid DCT-DWT Techniques	Hybrid	Combines DCT and DWT advantages	Improved compression and quality	Multimedia applications
12	Deep Learning Compression	AI-Based	Uses neural networks and autoencoders for compression	Adaptive and high-performance compression	AI systems, cloud storage
13	K-Means Clustering Compression	Hybrid	Groups similar pixels into clusters	Efficient segmentation-based compression	Nuclear medicine imaging
14	ROI Coding	Lossy	Compresses important regions with higher quality	Preserves critical image details	Medical diagnostics
15	Neural Network-Based Compression	AI-Based	Learns compact image representation automatically	Improved compression accuracy	Intelligent image processing systems

Investigate advancements in PNG compression using predictive coding and RLE, achieving improved compression efficiency without sacrificing data integrity. Their work reinforces the continued relevance of lossless methods in applications requiring exact reconstruction, such as medical and scientific imaging [11]. Compression methods are mainly categorized into Lossless Compression, where the original image is perfectly reconstructed, and Lossy Compression, where some data is removed but a much higher compression ratio is achieved. Popular techniques such as JPEG, PNG, Huffman Coding, Run Length Encoding (RLE), Discrete Cosine Transform (DCT), and Discrete Wavelet Transform (DWT) are widely used in real-world applications [2][3]. As the demand for high-quality images continues to increase across fields like multimedia, telemedicine, artificial intelligence, cloud storage, and remote sensing, image compression has become essential.

II. LITERATURE REVIEW

The present a comprehensive review of digital image processing techniques, highlighting the importance of compression as a core component in efficient image storage and transmission. Their study categorizes image compression into lossless and lossy techniques, emphasizing trade-offs between data reduction and image fidelity. Further analyze lossless image compression techniques, focusing on methods such as Run-Length Encoding (RLE), Huffman coding, and predictive coding. Their performance evaluation demonstrates that while lossless methods ensure exact reconstruction, they typically achieve lower compression ratios compared to lossy techniques [1][2].

Explore advancements in lossy compression, particularly transform-based methods like Discrete Cosine Transform (DCT) and Discrete Wavelet Transform (DWT). Their work highlights how modern techniques aim to balance compression efficiency with perceptual quality. A hybrid DCT-DWT model, showing enhanced performance for multimedia and digital photography applications [3][8][7]. Daubechies, and Symlet wavelets for MRI image compression, concluding that Daubechies wavelets provide better energy compaction and reconstruction quality, demonstrates the effectiveness of wavelet compression for 3D biological image datasets, especially in time-lapse microscopy. Analyze reversible (lossless) compression techniques for teleradiology, emphasizing the importance of preserving diagnostic information [5][12][11]. JPEG 2000 compression using Region of Interest (ROI) coding, enabling higher quality in diagnostically important areas while compressing less critical regions more aggressively [9].

Fractal image compression is particularly useful in medical imaging due to its ability to exploit self-similarity in images such as CT and MRI scans. However, its computational complexity remains a limitation [5]. A novel approach combining lossy compression with iterative reconstruction for encrypted images, addressing security concerns in image transmission [13]. The use of K-means clustering for image compression in nuclear medicine imaging, showing improved segmentation-based compression efficiency. Explore neural network-based compression using corner block techniques, representing early efforts toward intelligent compression systems [14]. A hybrid model integrating machine learning with JPEG compression, demonstrating improved efficiency and adaptability compared to traditional JPEG methods [6]. Hybrid approach combining Singular Value Decomposition (SVD) with DWT, demonstrating improved compression ratios while maintaining acceptable visual quality similarly hybrid DCT-DWT model, showing enhanced performance for multimedia and digital photography applications Wavelet-based compression has gained significant attention in medical imaging due to its multi-resolution capabilities[8]. Lossless Compression Enhancement by Investigate advancements in PNG compression using predictive coding and RLE, achieving improved compression efficiency without sacrificing data integrity. Their work reinforces the continued relevance of lossless methods in applications requiring exact reconstruction, such as medical and scientific imaging.[10].

III. METHODOLOGY

The methodology of digital image compression involves a sequence of image processing steps used to reduce image size while preserving visual quality. The process is shown in Table 2. The proposed workflow includes image acquisition, preprocessing, transformation, encoding, compression, and reconstruction stages.

Table 2. Process Description

Parameter	Description
Image Types	Natural, Medical, Satellite, Multimedia
Formats	JPEG, PNG, BMP
Resolution	256×256 to 1024×1024 pixels
Color Mode	RGB and Grayscale
Dataset Usage	Compression performance evaluation

IV. RESULT AND DISCUSSION

The present study focused on analyzing and comparing various Lossless and Lossy Image Compression Techniques used in Digital Image Processing. The primary aim was to understand how different methods affect Compression Ratio, PSNR (Peak Signal- to-Noise Ratio), and overall image quality. The analysis showed that Lossless compression techniques such as RLE, Huffman Coding, and PNG preserve the original image data completely. As a result, the image quality remains identical to the original, but the achieved compression ratio is relatively lower. In contrast, Lossy compression techniques such as JPEG and JPEG2000 remove certain redundant or less important information from the image. This leads to a significantly higher compression ratio, although a slight reduction in image quality is observed. Compression Ratio Comparison is shown in Table 3.

Table 3. Compression Ratio Comparison

Sr.No	Compression Technique	Compression Ratio	PSNR
1	RLE (Lossless)	1.4	∞
2	Huffman (Lossless)	1.6	∞
3	PNG (Lossless)	2.1	∞
4	JPEG (Lossy)	8.5	32.4
5	JPEG2000 (Lossy)	10.2	34.7

Interpretation of Results

- Lossless techniques produce a PSNR of ∞ because there is no loss of information.
- Among lossless methods, PNG achieved the highest compression ratio.
- Lossy techniques like JPEG and JPEG2000 achieved significantly higher compression ratios, making them more suitable for storage- and bandwidth- intensive applications. JPEG2000 provided the best balance between compression efficiency and image quality, delivering both high compression ratio and good PSNR values.

The Compression Ratio Comparisons is shown in Fig 1.

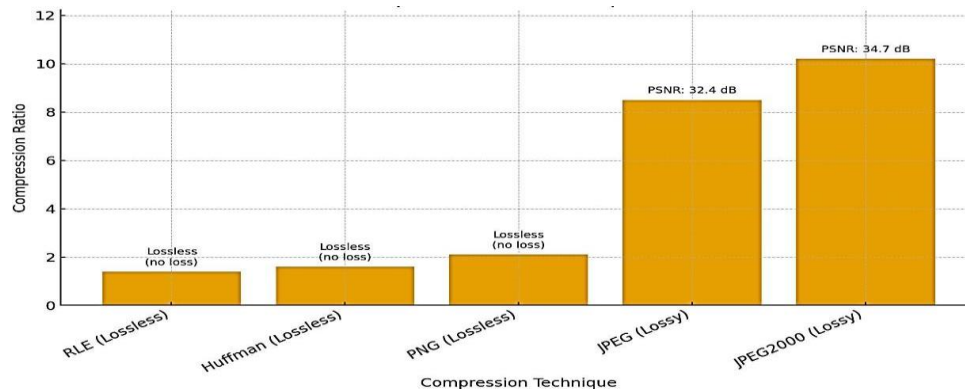


Fig 1. Compression Ratio Comparisons

V. FUTURE WORK

Future research in digital image processing and image compression techniques can focus on developing more intelligent, efficient, and adaptive compression models capable of handling the growing demand for high-resolution image data. Emerging technologies such as Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning have shown promising results in improving compression efficiency while maintaining superior image quality. Future systems may integrate neural networks with traditional compression methods like DCT, DWT, and JPEG to achieve better compression ratios with reduced computational complexity. Another important area for future work is real-time image compression for applications such as telemedicine, autonomous vehicles, video surveillance, cloud computing, and remote sensing. Researchers can also focus on energy-efficient and low-latency compression algorithms suitable for mobile devices and Internet of Things (IoT) environments. In medical imaging, future compression techniques should aim to preserve diagnostic accuracy while reducing storage and transmission requirements. Advanced ROI-based compression and secure encrypted image compression methods can further improve privacy and reliability in healthcare systems.

Additionally, adaptive and content-aware compression systems can be developed to automatically select the most suitable compression technique based on image characteristics. Hybrid models combining wavelet transforms, clustering methods, and deep learning approaches are expected to provide enhanced performance in terms of compression ratio, image quality, and processing speed.

VI. CONCLUSION

The study concludes that Lossless Compression is ideal when image quality must remain absolutely unchanged, whereas Lossy Compression is more effective when storage space and transmission speed are the main priorities. JPEG2000 emerged as the most efficient technique due to its superior balance of compression performance and retained image quality. This review paper presented a comprehensive analysis of various image compression techniques used in digital image processing. The study examined both lossless and lossy compression approaches, including traditional transform-based methods and modern artificial intelligence-based techniques.

Lossless compression methods such as PNG, Huffman Coding, and Run Length Encoding preserve image quality perfectly and are suitable for applications requiring exact reconstruction. However, these techniques generally provide lower compression ratios. Lossy compression methods such as JPEG and JPEG2000 achieve significantly higher compression efficiency by removing less important image information. Among the reviewed techniques, JPEG2000 demonstrated superior performance in terms of compression ratio and reconstructed image quality. The study also highlighted the growing importance of hybrid and deep learning-based image compression systems. Future image

compression technologies are expected to provide adaptive, intelligent, and secure solutions for large-scale multimedia and medical imaging applications.

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