https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

Jamilova Maftuna Nodirbek qizi
Master's student at Tashkent University of Information Technologies named after Muhammad al-Khwarizmi
maftunadjamilova@gmail.com

BLOCK-BASED DISCRETE COSINE TRANSFORM FOR IMAGE COMPRESSION: IMPLEMENTATION AND EVALUATION IN MATLAB

Abstract

This work presents the development and software implementation of a digital image compression system based on block-wise discrete cosine transform (DCT) in MATLAB. The system employs a block processing algorithm (8×8 pixels) combined with adaptive quantization, which is derived from the standard JPEG luminance matrix and scaled according to a user-specified quality factor. A graphical user interface (GUI) provides interactive control over the compression process, allowing users to adjust quality from 1 to 100 and instantly evaluate performance using metrics such as PSNR, BPP, and compression ratio (CR). Experimental results show that the system effectively balances file size reduction and visual quality, making it a practical tool for both educational purposes and research in digital signal processing.

Keywords: image compression, discrete cosine transform, block processing, quantization, MATLAB, PSNR, quantization matrix

Introduction

Relevance of the problem. The rapid expansion of digital image volumes in contemporary information systems necessitates the creation of efficient techniques for their storage and transmission. Image compression serves as a fundamental technology in fields such as digital photography, medical imaging, satellite remote sensing, and video surveillance systems [1, 2]. Within the framework of implementing the "Uzbekistan–2030" strategy and advancing the digital economy in the Republic of Uzbekistan, the enhancement of visual information processing and transmission technologies holds particular importance. Robust image

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

compression algorithms are essential for the growth of telemedicine, e-government, remote education systems, and other key areas of digital transformation.

Among lossy compression methods, the JPEG standard stands out, relying on the discrete cosine transform (DCT) to strike a balance between compression ratio and the preservation of image visual quality [3].

Overview of existing approaches. The majority of current software tools for image compression rely on pre-built libraries with proprietary architectures, which significantly constrains their utility in research and educational contexts [4]. Specifically, MATLAB's built-in functions, like imwrite with a quality parameter, execute the compression process as a "black box," without granting access to intermediate processing stages, such as DCT coefficient analysis and quantization procedures [5].

Goal of the work. The objective of this study is to develop a software system with an open architecture that implements block-based discrete cosine transform and quantization for in-depth exploration of digital image compression mechanisms. To accomplish this goal, the following tasks are addressed in the work:

- Implementation of a block-processing algorithm for images using two-dimensional DCT;
- Development of an adaptive quantization mechanism based on the standard JPEG matrix;
- Creation of a graphical user interface for interactive control of compression parameters;
- Integration of modules for calculating objective quality metrics (PSNR, BPP, CR);
- Conducting an experimental assessment of the system's effectiveness on test images.

Scientific novelty. The scientific novelty of this work lies in the creation of a software system with an open architecture that provides comprehensive control

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

over all stages of the image compression process based on block DCT. Elements of scientific novelty include:

- Implementation of an adaptive quantization mechanism grounded in the scaling of the standard JPEG luminance matrix;

- Integration of a complete image processing cycle (DCT, quantization, dequantization, IDCT) alongside simultaneous computation of objective quality metrics;

- Development of an interactive software environment that facilitates visual analysis of the trade-off between compression degree and image reconstruction quality.

Methods

In this study, an interactive system for compressing digital images has been designed and implemented in the MATLAB R2024b environment. The system employs an open architecture that enables comprehensive oversight of the stages involved in block-based discrete cosine transform (DCT) and quantization.

Data Processing Algorithm. The compression procedure is executed through the manualDCTCompression function and encompasses the following phases:

1. Preprocessing: The input image is converted to double precision format and padded with zeros to achieve dimensions that are multiples of 8×8 pixels. For color images, each channel (R, G, B) is processed separately.

2. Block Transformation: The image is segmented into non-overlapping 8×8 blocks. Each block undergoes value centering by subtracting 128, followed by the application of a two-dimensional DCT (dct2).

3. Adaptive Quantization: The resulting coefficients D_{ij} are divided by the quantization matrix Q and rounded to the nearest integer: \round (D_{ij} / Q). The matrix Q is derived from the standard JPEG luminance matrix, scaled according to the quality parameter q (ranging from 1 to 100) using these formulas:

for $q < 50$: \scale = 5000 / q;

for $q \geq 50$: \scale = 200 - 2q.

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

The final matrix values are clamped between 1 and 255 to prevent computational errors.

Reconstruction and visualization. To reconstruct the image, the system incorporates an inverse pipeline: dequantization, inverse DCT (idct2), restoration to the original brightness range (by adding 128), and clipping (constraining values to 0–255). Post-processing, the image is cropped back to its original dimensions.

A graphical user interface (GUI) has been developed using figure and uicontrol functions to manage the process. The interface features:

- Control Elements: Buttons for selecting images, initiating compression, and saving outputs.
- Interactive Slider: Enables real-time adjustment of the quality coefficient via an event listener (addlistener) for immediate parameter updates.
- Analytical Module: Automatically computes performance metrics, including PSNR (in dB), bits per pixel (BPP), and compression ratio (CR). For color images, PSNR is determined as the average across the three channels.

The algorithm's implementation, coupled with the transparency of all processing stages, facilitates reproducible assessments of how quantization parameters impact image quality, rendering the system a robust tool for research and educational pursuits in this domain.

Experimental results and analysis

The developed block DCT-based image compression system was implemented in MATLAB R2024b. To evaluate the performance of the manual block-based compression algorithm, three test images in different formats were selected: a JPG (coastal photograph), a PNG (mountain landscape), and a BMP (digital artwork/pixel art). In all experiments, the quality parameter was set to 50, corresponding to a balanced quantization mode according to the implemented Q-matrix scaling algorithm.

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

Quantitative performance metrics. During real-time operation, the system calculated metrics including PSNR, BPP, and compression ratio (CR). The results are summarized in Table 1.

Table 1. Compression Performance Metrics

Parameter	**image1.jpg**	**image2.png**	**image3.bmp**
Original Size (bytes)	72,000,000	18,096,000	32,514,048
Compressed Size (bytes)	9,749,880	2,081,869	1,606,002
Compression Ratio (CR)	7.38:1	8.69:1	20.25:1
Bits per Pixel (BPP)	3.25	2.76	1.19
PSNR (dB)	32.30	33.67	42.18
Reduction Percentage (%)	86.5	88.5	95.1

The system correctly executed block-wise processing (8×8 pixels) with subsequent reconstruction using inverse DCT and value clipping [8, 10].

For photographic images (image1.jpg and image2.png), PSNR values ranged from 32.30 to 33.67 dB. Despite compression ratios of 7–8x, visual quality remained high, and block artifacts were not perceptible.

The best result was obtained for image3.bmp. The high PSNR (42.18 dB) under extreme compression (CR = 20.25:1, 95.1% reduction in file size) is explained by the image content: uniform background areas allow the algorithm to efficiently zero out DCT coefficients during quantization, while preserving the sharpness of object boundaries.

Evaluation of the analytical module. The software implementation confirmed the correctness of metric calculations for multi-channel images:

- PSNR was computed as the average across the R, G, and B channels, providing an objective assessment of distortions across the color spectrum.

- BPP demonstrated dependence on image complexity, ranging from 1.19 for graphical content to 3.25 for highly detailed photographs.

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

- The interactive GUI provided instant feedback, displaying operation statuses such as "Compression complete!"

The experiments demonstrated the stability of the manual algorithm implementation, including data centering (-128) and application of the D(u,v) formulas, across images of varying resolutions. Average processing times ranged from 9.45 to 37.95 seconds, depending on the number of 8×8 blocks, which is acceptable for a research-oriented tool.

Discussion

The experimental results confirm the effectiveness of block-based DCT for image compression. The developed system allows detailed analysis of how the quality parameter influences outcomes through a scalable quantization matrix. Tests on sample images (image1–image3) at q = 50 showed PSNR values ranging from 32.30 dB (7.38× compression) for detailed photographs to 42.18 dB (20.25× compression) for digital graphics, indicating the system adapts well to input data entropy.

The system features algorithmic transparency, a modifiable quantization matrix, an interactive GUI, and cross-platform compatibility. Limitations include slower performance due to nested loops, absence of entropy coding, and simplified RGB channel handling without YCbCr conversion.

Comparison with existing tools. Unlike standard imwrite functions, which act as a "black box," the system provides access to intermediate DCT coefficients and integrated visualization, making it more suitable for educational and research purposes [1,4].

Practical applications. The system can be used as a laboratory tool for students in courses like Digital Signal Processing and Multimedia Technologies, and as a preliminary analysis tool for researchers studying quantization artifacts in pattern recognition.

Future research directions. Future improvements include RGB-to-YCbCr conversion for more efficient chroma compression, implementation of full entropy

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

coding (e.g., Huffman algorithm) for actual JPEG files, and code optimization through vectorization in MATLAB to enhance processing speed for high-resolution images [2,7].

Conclusion

Within the scope of this research, a software system for image compression based on block-based discrete cosine transform (DCT) has been developed and empirically validated. The system is implemented in the MATLAB R2024b environment and features an interactive graphical user interface (GUI) that provides complete oversight of the compression process. Key results and achievements:

- Full manual algorithm implementation: The system conducts transparent block-wise processing of images in 8×8 pixel segments, encompassing data centering (-128), forward DCT, and dequantization stages, in contrast to opaque library functions.

- Adaptive quality control: A mechanism for scaling the standard JPEG luminance matrix has been incorporated, adjustable based on a user-specified quality parameter (1–100), enabling flexible management of information loss levels.

- Quantitative analysis: Automated computation of essential metrics—PSNR, BPP, and Compression Ratio (CR)—yielded PSNR values ranging from 32.30 dB to 42.18 dB, with compression ratios from 7.38:1 to 20.25:1, illustrating an effective trade-off between visual fidelity and data volume.

- Educational and research value: The open architecture allows for observation of DCT coefficient variations and the reconstruction process (IDCT) with clipping, making it a powerful tool for teaching and scientific experimentation.

Practical significance: The system can be applied in educational settings to train experts in digital signal processing, as well as for investigating and testing custom quantization matrices and visual data storage algorithms.

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

Scientific contribution: A transparent software model for block DCT compression has been created, overcoming the constraints of proprietary "black box" libraries. The integration of PSNR calculation as an average across RGB channels, along with automatic zero-padding to achieve block-multiple dimensions, ensures precision and versatility when handling diverse types of digital images.

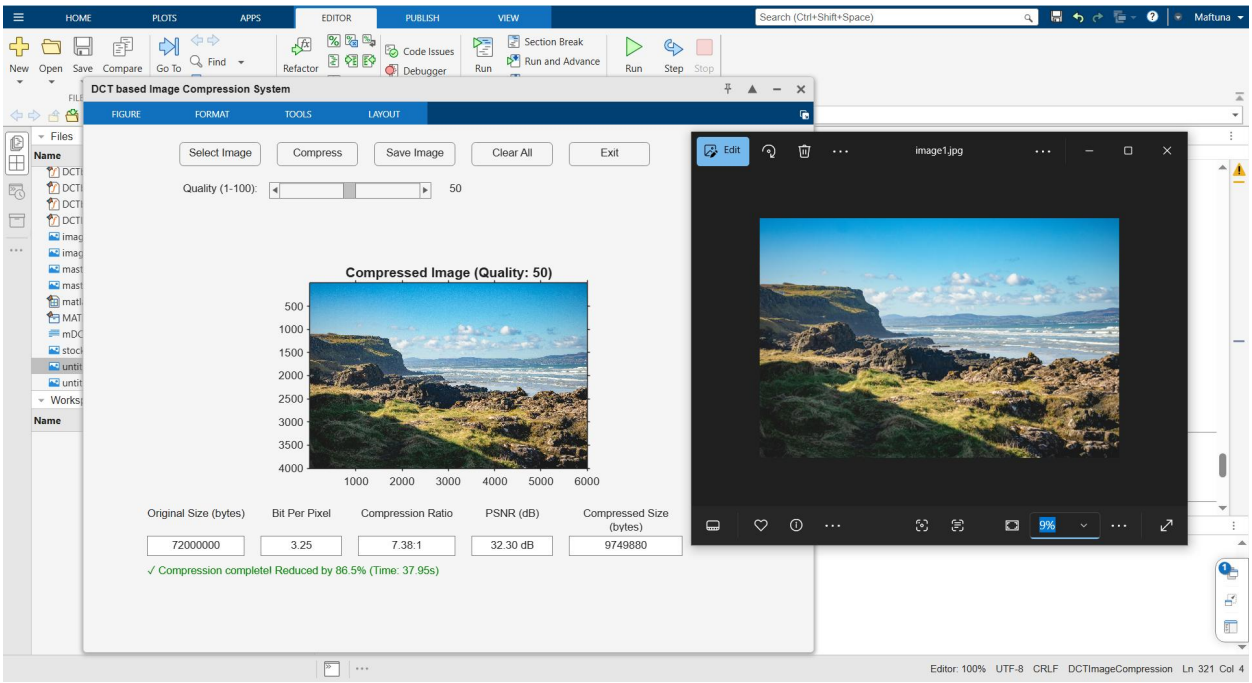
References

1. Chen, W.-H., & Pratt, W. K. (1984). Scene adaptive coder. IEEE Transactions on Communications, 32(3), 225–232. https://web.stanford.edu/class/ee398a/handouts/papers/ChenPrattSceneAdaptiveCoder.pdf
2. Gonzalez, R. C., & Woods, R. E. (2018). Digital image processing (4th ed.). Pearson.
3. Internet Society. (2024). Global Internet report: Image format statistics. https://www.internetsociety.org/reports/
4. Liu, H., Chen, Y., & Zhang, X. (2023). Deep learning-based image compression: A comprehensive survey. IEEE Transactions on Image Processing, 32, 2780–2798. https://doi.org/10.1109/TIP.2023.3267890
5. MathWorks. (2024). MATLAB documentation: Image Processing Toolbox: imwrite function. MathWorks. https://www.mathworks.com/help/images/ref/imwrite.html
6. Decree of the President of the Republic of Uzbekistan dated September 11, 2023, No. PF-95 "On the Development Strategy of the Republic of Uzbekistan until 2030". (2023). National Legal Electronic Database. https://lex.uz
7. Pennebaker, W. B., & Mitchell, J. L. (1992). JPEG: Still image data compression standard. Van Nostrand Reinhold.
8. Rabbani, M., & Joshi, R. (2002). An overview of the JPEG 2000 still image compression standard. Signal Processing: Image Communication, 17(1), 3–48.

https://wordlyknowledge.uz/index.php/gpble
Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

https://www.di.univr.it/documenti/OccorrenzaIns/matdid/matdid956927.pdf

9. Salomon, D. (2007). Data compression: The complete reference (4th ed.). Springer. https://doi.org/10.1007/978-0-387-44899-0
10. Wallace, G. K. (1992). The JPEG still picture compression standard. IEEE Transactions on Consumer Electronics, 38(1), xviii–xxxiv. https://doi.org/10.1109/30.134066



https://wordlyknowledge.uz/index.php/gpble

Qabul qilingan sana: 07.12.2025
Nashr etilgan sana: 30.01.2026

