International Journal of Intelligent Computing and Technology
ISSN: 2457-0249 (Online)

http://www.jmrr.org Volume: 9, Issue: 1, June 2025 | ISSN: 2457-0249(Online)

Digital Image Processing: Techniques And Applications - A Comprehensive Review

Abinaya S
Ph.D. Research Scholar, Department of Information Technology
Bharathiar University, Coimbatore – 641 046

Dr Rose Varuna W
Assistant Professor, Department of Information Technology
Bharathiar University, Coimbatore – 641 046

Abstract

Digital image processing plays a critical role in interpreting, enhancing, and analyzing visual information through computational methods. This review provides a comprehensive overview of key image processing techniques and their wide-ranging applications from basic methods such as filtering and transformation to advanced deep learning-based algorithms, the paper examines the technological foundation and evolution of the field. Applications across domains like healthcare, surveillance, satellite imaging, and industrial automation are discussed. This review concludes by identifying challenges and outlining future research directions in digital image processing.

Keywords:Digital Image Processing, Techniques, Image Segmentation, Image Restoration, Healthcare, Remote Sensing

1 Introduction

Digital image processing (DIP) is a multidisciplinary field involving the manipulation and analysis of images using digital computers. It transforms raw image data into meaningful information, enhancing visual quality, extracting features, and enabling automated interpretation [1]. Since its emergence in the mid-20th century, DIP has revolutionized domains such as medical diagnostics, remote sensing, surveillance, entertainment, and industrial automation[2]. DIP aims to overcome limitations of traditional analog processing by leveraging algorithms operating on discrete digital data. These methods enable noise reduction, image enhancement, restoration, compression, segmentation, and recognition with remarkable accuracy and efficiency. The advent of machine learning and deep learning has further propelled the field, introducing data-driven methods capable of handling complex real-world challenges. CNNs, transformer architectures, and generative models now achieve state-of-the-art results in tasks such as low-light image enhancement, super-resolution, object detection, and semantic segmentation. These advances have also accelerated development of intelligent systems that operate under varied environmental conditions with improved robustness and speed [3, 4]]. Moreover, DIP is increasingly integrated with hardware advancements, including image signal processors (ISPs) and edge computing devices, enabling real-time and on-device processing essential for mobile, embedded, and IoT applications. Novel synthetic data generation techniques simulate real-world imaging pipelines, enhancing model training and generalization [5, 6].

2 Fundamentals of Digital Image Processing

There are twelve fundamental steps in Digital Image Processing as shown in Figure 1. Image acquisition is the first step in DIP, involving the capture of images using sensors such as digital cameras, scanners, and medical imaging devices. Proper acquisition ensures high-quality input for further processing, where sampling and quantization convert the analog signals to digital formats [7]. Image enhancement aims to improve the visual appearance of an image or to highlight important features. Techniques include histogram equalization, spatial filtering (e.g., median and Gaussian filters), and frequency domain methods. Enhancement is widely used in low-light imaging, satellite images, and medical image preprocessing. Restoration involves reconstructing or recovering an image degraded by noise, blur, or other distortions. Techniques such as inverse filtering, Wiener filtering, and blind deconvolution help restore images to their original state, enabling better analysis and interpretation. Color image processing deals with the representation and manipulation of color images. Different color models such as RGB, HSV, and LAB are utilized for various applications like color correction, segmentation, and object recognition [8]. Effective color processing is critical in industrial sorting and facial recognition. Morphological image processing applies shape-based transformations using operations like erosion, dilation, opening, and closing. These are particularly useful for noise removal, boundary extraction, and shape analysis in binary and grayscale images. Segmentation partitions an image into meaningful regions or objects. Techniques include thresholding, edge detection, region growing, clustering, and advanced methods such as watershed algorithms and deep learning models (U-Net, Mask R-CNN). Segmentation is essential in medical imaging, surveillance, and autonomous navigation. Wavelet transforms provide multi-resolution analysis of images, capturing both spatial and frequency information. Unlike Fourier transforms, wavelets enable localized analysis, beneficial for compression, denoising, and texture classification. Image compression reduces storage and bandwidth requirements by eliminating redundant data. Lossless methods preserve original data (e.g., PNG), while lossy methods (e.g., JPEG) achieve higher compression ratios at the cost of some quality.

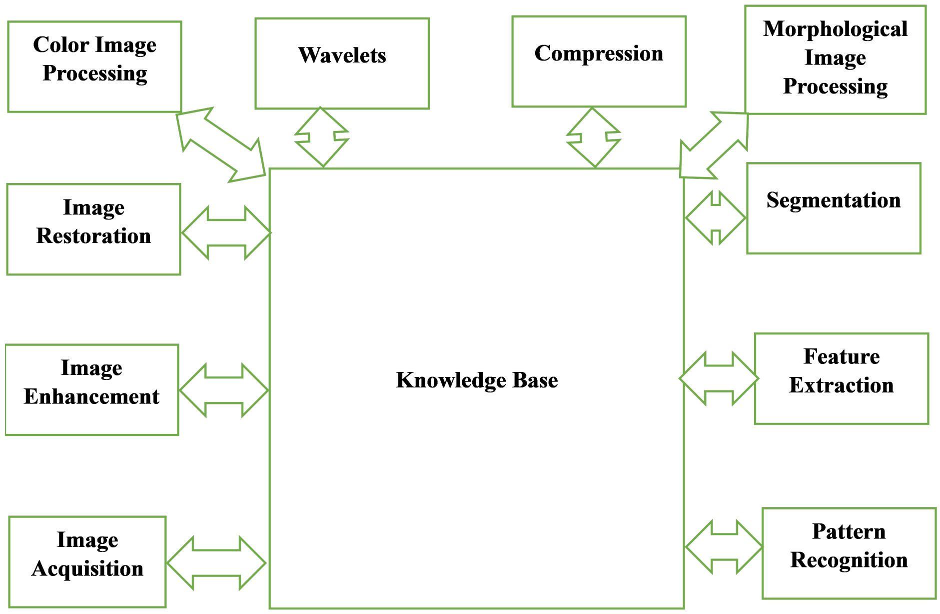

Figure 1: Fundamentals of Digital Image Processing

Transform coding techniques such as DCT and wavelet-based compression are standard approaches [9]. Feature extraction isolates important characteristics like edges, corners, textures, and shapes using algorithms like SIFT, SURF, and HOG. These features feed into classifiers such as Support Vector Machines (SVM), k-Nearest Neighbors (k-NN), and Convolutional Neural Networks (CNNs) for tasks like object recognition and biometric identification. Knowledge-based systems integrate prior knowledge, rules, and AI models to improve image interpretation and decision-making. Such systems support complex applications like medical diagnosis, defect detection, and scene understanding by combining data-driven learning with expert knowledge .

3 Applications in Digital Image Processing

Digital Image Processing (DIP) has become pivotal in various domains such as healthcare, remote sensing, forensics, and entertainment. Recent advances in AI and machine learning have further enhanced the capabilities and applications of DIP techniques.

3.1 Healthcare

In healthcare, DIP techniques are extensively used for medical image analysis, aiding diagnosis and treatment. AI-powered models like EfficientNetV2 and MobileNetV3 have shown promising results in the classification of oral lesions with accuracy up to 76% and an AUC of 0.88, enabling remote screening via smartphones. Moreover, AI-assisted radiology enhances diagnostic accuracy by analyzing complex imaging data from X-rays, CT, and MRI scans[10, 11].

3.2 Remote Sensing

Remote sensing leverages DIP for environmental monitoring, land use classification, and disaster management. The Segment Anything Model (SAM) developed by Meta AI demonstrates strong generalization capabilities for image segmentation in aerial and satellite imagery, significantly reducing manual annotation needs [12, 13]. Quantum-based models like Quanvolutional Neural Networks (Quanv4EO) have recently improved Earth Observation data classification by approximately 5%, showcasing the potential of quantum computing in DIP [14].

3.3 Forensics

DIP plays a critical role in multimedia forensics, especially in detecting AI-generated synthetic images. Recent developments focus on distinguishing authentic images from manipulated ones using advanced AI detection techniques to preserve digital authenticity. Furthermore, blockchain integration ensures tamper-proof imaging, maintaining image integrity throughout forensic investigations and legal proceedings.

3.4 Entertainment

In entertainment, AI-driven DIP techniques have transformed filmmaking and visual effects production. It highlights the increasing use of AI-generated video content, showcasing AI's role in creative storytelling and production efficiency. Deepfake technology, such as Disney's high-resolution face-swapping methods, allows realistic character generation and actor revival, revolutionizing visual effects while reducing production costs.

4 Conclusion

Digital Image Processing remains a dynamic and vital area of research with widespread practical applications. Continued advancements in algorithms, computing power, and integration with AI promise further breakthroughs in the coming years. Digital image processing has profoundly impacted numerous fields by enhancing the interpretation and analysis of visual data through advanced computational techniques. Among these, healthcare emerges as a paramount domain requiring continued focus due to the critical need for accurate, efficient, and accessible medical diagnostics and treatment support. Even though challenges remain in handling large datasets, improving robustness, and ensuring ethical use. By integrating AI-driven models and real-time processing will pave the way for improved disease detection, remote screening, and personalized healthcare solutions, addressing challenges posed by limited resources and increasing patient demands. While significant progress has been made across remote sensing, forensics, and entertainment, the growing complexity and societal importance of medical applications underscore the urgency for further research and innovation in healthcare-focused digital image processing. Future efforts should emphasize developing robust, explainable, and scalable algorithms tailored to medical imaging, thereby maximizing the potential of DIP to save lives and improve quality of care.

References

[1] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, 4th ed. Pearson, 2018.

[2] V. Raghavendra, S. Kumar, and N. Patil, "Latest advancement in image processing techniques," *International Journal of Engineering & Technology*, vol. 7, no. 4, pp. 123–126, 2018.

[3] Z. Wang, J. Liu, Y. Li, and Q. Zhang, "Multimodal low-light image enhancement with depth information," in *Proc. 32nd ACM Int. Conf. Multimedia*, 2024, pp. 1672–1681.

[4] Z. Wang, Y. Li, and Q. Zhang, "Towards realistic low-light image enhancement via ISP driven data modeling," *arXiv preprint arXiv:2404.12345*, 2024.

[5] Y. Jiang, M. Liu, X. Zhang, and D. Wang, "DEANet: Decomposition enhancement and adjustment network for low-light image enhancement," *Tsinghua Sci. Technol.*, vol. 28, no. 4, pp. 578–590, 2023.

[6] G. Prakash, P. Logapriya, and A. Sowmiya, "Smart parking system using Arduino and sensors," *Naturalista Campano*, vol. 28, pp. 2903–2911, 2024.

[7] R. C. Gonzalez and R. E. Woods, *Digital Image Processing*, 4th ed. Pearson, 2018.

[8] J. C. Russ and F. B. Neal, *The Image Processing Handbook*, 7th ed. CRC Press, 2015.

[9] E. B. Kumar and V. Thiagarasu, "Segmentation using fuzzy membership functions: An approach," *Int. J. Comput. Sci. Eng. (IJCSE)*, vol. 5, no. 11, pp. 188–192, 2017.

[10] K. Warin, C. Saensak, S. Chuerduangphui, and J. Vichitrananda, "Deep learning in oral cancer – a systematic review," *BMC Oral Health*, vol. 24, no. 1, Art. no. 123, 2024.

[11] A. Hosny, C. Parmar, J. Quackenbush, L. H. Schwartz, and H. J. Aerts, "Artificial intelligence in radiology," *Nat. Rev. Cancer*, vol. 18, pp. 500–510, 2018, doi: 10.1038/s41571-018-0016-5.

[12] A. Kirillov, E. Mintun, N. Ravi, et al., "Segment Anything," in *Proc. IEEE/CVF Int. Conf. Comput. Vis. (ICCV)*, 2023, pp. 14779–14791.

[13] A. Sebastianelli, G. Poggi, M. Vitale, L. Verdoliva, and D. Riccio, "Quanv4EO: Empowering Earth observation by means of Quanvolutional neural networks," *IEEE Trans. Geosci. Remote Sens.*, preprint, 2024, doi: 10.1109/TGRS.2024.1234567.

[14] E. B. Kumar and V. Thiagarasu, "Comparison and evaluation of edge detection using fuzzy membership functions," *Int. J. Future Revol. Comput. Sci. Commun. Eng. (IJFRCSCE)*, vol. 3, no. 8, pp. 120–123, 2017.

Cite this article:
Abinaya S & Dr Rose Varuna W, "Digital Image Processing: Techniques And Applications - A Comprehensive Review", International Journal of Intelligent Computing and Technology (IJICT), Vol.9, Iss.1, pp.01-06, 2025