Journal of Innovative and Creativity
Journal Homepage: https://joecy.org/index.php/joecy
e-mail: journaljoecy@gmail.com

Faculty of Education
University of Pahlawan Tuanku Tambusai
ISSN 2775-771X (Online)
ISSN 2962-570X **(Printed)**
5 (3) 2025, Page 12835-12842

A Review of Trends and Developments in Document Image Compression Methods from 2016 to 2025

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Published: Oktober, 2025

ABSTRAK

Penelitian ini bertujuan untuk menganalisis dan mengklasifikasikan perkembangan penelitian dalam kompresi citra dokumen dari tahun 2016 hingga 2025, mengidentifikasi metode yang berlaku, karakteristik teknis, dan tren kronologis. Sebanyak 56 artikel jurnal diambil dari basis data ScienceDirect menggunakan kata kunci "kompresi citra dokumen," "kompresi citra teks," dan istilah terkait, terbatas pada publikasi berbahasa Inggris dalam Ilmu Komputer, Pemrosesan Sinyal, dan Pemrosesan Citra. Pemilihan mengikuti identifikasi proses tiga tahap, penyaringan relevansi, dan klasifikasi metodologis yang menghasilkan enam makalah yang secara langsung berfokus pada kompresi citra dokumen. Hasilnya mengungkapkan tiga fase utama pengembangan: metode transformasi klasik (2016-2018) seperti JPEG2000, SPIHT, Chain Code, JBIG, JBIG2, dan JPEG-LS; pendekatan kompresi peningkatan hibrida (2017-2019) termasuk model kolaboratif DjVu dan PDE; dan kerangka kerja pembelajaran (2019-2025) yang menampilkan Autoencoder, VAE, GAN, Transformer, dan JPEG AI. Secara keseluruhan, bidang ini telah berevolusi dari transformasi matematika tradisional menjadi model data adaptif. Meskipun penelitian yang secara khusus menargetkan citra dokumen masih terbatas, metode neural dan hibrida yang muncul menyoroti meningkatnya perhatian terhadap pelestarian keterbacaan, kompatibilitas OCR, dan pengarsipan digital yang efisien.

Kata kunci: Kompresi citra dokumen, Metode transformasi, Pendekatan hibrida, Kerangka kerja pembelajaran.

ABSTRACT

This study aimed to analyze and classify research developments in document image compression from 2016 to 2025, identifying prevailing methods, technical characteristics, and chronological trends. A total of 56 journal articles were retrieved from the ScienceDirect database using the keywords "document image compression," "text image compression," and related terms, limited to English language publications in Computer Science, Signal Processing, and Image Processing. The selection followed a three stage process identification, relevance screening, and methodological classification resulting in six papers directly focused on document image compression. The results revealed three main phases of development: classical transform methods (2016-2018) such as JPEG2000, SPIHT, Chain Code, JBIG, JBIG2, and JPEG-LS; hybrid enhancement compression approaches (2017-2019) including DjVu and PDE collaborative models; and learning frameworks (2019-2025) featuring Autoencoder, VAE, GAN, Transformer, and JPEG AI. Overall, the field has evolved from traditional mathematical transforms to adaptive, data models. While research specifically targeting document images remains limited, emerging neural and hybrid methods highlight growing attention to readability preservation, OCR compatibility, and efficient digital archiving.

Keywords: Document image compression, Transform methods, Hybrid approaches, Learning frameworks.

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INTRODUCTION

The swift proliferation of digital files, encompassing both digitized and originally digital materials, has been propelled by technological progress and the influence of the COVID-19 pandemic, which expedited the transition to digital record keeping for retaining and sharing knowledge. Converting to

digital formats enhances accessibility, productivity, and yields considerable advantages and financial gains, notably when coupled with cloud document management platforms (Williams, 2022). However, substantial storage demands and transfer difficulties arise due to large file sizes across various fields. Performance issues occur in IoT environments when transmitting massive volumes of data over limited bandwidth, requiring filtering, optimization, and compression at the network edge to reduce latency and improve responsiveness (Mapari et al., 2024). Database systems face similar challenges when handling Large Objects (LOBs) ranging from 2 to 8 GB, necessitating specialized big data setups to maintain format and content integrity during processing and transfers (Lazarova, 2023). Modern electron microscopy exemplifies these issues, as individual acquisition sessions generate terabyte sized files, creating significant difficulties in data transfer, computation, and management that require efficient and sustainable solutions (Poger et al., 2023).

To proficiently oversee multifaceted documents that integrate assorted content types like visuals, figures, and written content, strategies have been formulated to adeptly process disparate file elements (El-Omari, 2020). Methodologies aimed at diminishing image dimensions and refining storage configurations stand as fundamental for streamlined archiving and dissemination by discarding superfluous data and superfluous picture components (Qasim et al., 2020). Image diminishing procedures constitute a pivotal function in the productive archiving and conveyance of data across a spectrum of utilizations, spanning from online networking platforms to medical imaging and handling of satellite sourced information (Mobeen et al., 2021). Machine learning concepts are progressively implemented within assorted diminishing activities, inclusive of satellite derived imagery, medical grade imagery, and textual documents (Ali & P. R, 2021). Acknowledging the swift proliferation of computerized documents and the heightened necessity for archiving and transmission effectiveness, grasping the tactics utilized for diminishing document imagery remains paramount. Consequently, this manuscript endeavors to scrutinize methodologies for diminishing document imagery documented within the ScienceDirect database spanning 2016 to 2025, encompassing both time honored procedures and cutting edge methodologies rooted in profound learning.

METHOD

This research adopted a descriptive qualitative strategy, utilizing a methodical examination of existing published works to explore how document image compression strategies advanced from 2016 to 2025. The purpose was to detect, arrange into groups, and contrast the procedures employed for decreasing document image dimensions for reasons related to digital archiving and sending. The selection of this framework was made to deliver an all of encompassing synopsis of the scholarly setting, register innovative patterns spanning from established transform oriented methods to strategies propelled by deep learning, and uncover areas needing further study in the field of compressing document images.

Data Source and Retrieval Process

The main collection of information came from the ScienceDirect database, which is a source of journals that have been reviewed by experts in fields like Computer Science, Signal Processing, and Image Processing. The process of finding relevant publications occurred in September of 2025, and it was done using this specific search phrase ("document image compression" OR "text image compression" OR "scanned document compression" OR "document compression" OR "text and graphics compression"). The search was restricted to the parameters summarized in Table 1.

Table 1. Search parameters used in ScienceDirect

Parameter	Specification
Publication year range	2016 to 2025
Publication type	Journal articles (research articles)
Language	English
Main subject areas	Computer Science, Signal Processing, Image Processing

The initial query returned 56 articles. All metadata including title, author(s), abstract, and citation information were exported in text format and stored for detailed analysis.

Screening and Selection Procedure

The retrieved articles were subjected to a three stages screening process to ensure thematic relevance. The steps are described as follows:

1. Initial Identification

All 56 retrieved records were screened by title, keywords, and abstract. Articles containing key terms such as document image, handwritten, historical document, scanned document, or binary image compression were retained for further review.

2. Technical Relevance Assessment

Abstracts and methodological sections were examined to determine whether the paper; explicitly addressed document image compression, or presented a compression algorithm applicable to document data (e.g., JPEG2000, DjVu, JBIG, SPIHT, Autoencoder, etc.). Then, articles focusing on unrelated domains such as medical, satellite, hyperspectral, or text data compression were excluded.

3. Methodological Classification

The selected articles were then grouped into distinct methodological categories:

a. Transform compression (DCT, DWT, Wavelet, JPEG2000, SPIHT)
b. Segmentation hybrid compression (DjVu, PDE combined with JPEG2000/JPEG-XR)
c. Lossless binary document codecs (JBIG, JBIG2, JPEG-LS, CALIC, Run-Length)
d. Contour compression (Chain code + Context mixing)
e. Learning compression (Autoencoder, VAE, GAN, Transformer models)

Validity and Limitations

Two-stage verification procedure was implemented. First, the search results were revalidated against the original query and filter parameters. Second, each article's method section was checked to confirm the presence of image compression techniques applicable to documents.

However, the study acknowledges several limitations:

1. Articles that mentioned document compression in a textual or general sense (without image data) were excluded.
2. The scope was confined to peer reviewed journal articles indexed in ScienceDirect, excluding conference proceedings and book chapters (except Sayood, 2018, which is a foundational text).
3. The analysis was qualitative; no citation metrics or statistical bibliometric indicators were computed.

Table 2. Summary of Screening Results

Screening Stage	Number of Articles	Description
Initial retrieval (Science Direct)	56	All articles under Computer Science, Signal, and Image Processing (2016-2025)
Relevant to documer image compression	6	Focused on scanned, handwritten, or historical document image compression
Non relevant (natura medical, satellite, or nor image)	50	Excluded from the final synthesis

FINDING AND DISCUSSION

This study examined 56 journal articles indexed in ScienceDirect between 2016 and 2025 that matched the search criteria related to document image compression. The purpose was to map the evolution of methods, ranging from traditional transform approaches to modern deep learning frameworks. Out of all retrieved papers, 6 articles (10.7%) were directly related to document image compression, while the remaining 50 articles (89.3%) focused on image compression in other domains, including natural scenes, medical imaging, satellite data, and general multimedia compression. This distribution indicates that research specifically targeting document image compression remains relatively underexplored, despite its critical role in digital archiving, scanning, and historical document preservation.

The relevant publications were grouped according to their methodological approaches. Table 3. presents the summary of identified categories, number of articles, publication years, and short descriptions of each method.

Table 3. Categories of document image compression methods (2016-2025)

Method	Sum	Year(s)	Data Type	References	Brief Description
DjVu/ Joint Enhancement– Compression	1	2016	Handwritten / Historical Document Images (DIBCO)	Yagoubi, Serir, & Beghdadi (2016)	Combines foreground–background segmentation based on orientation and contrast with the DjVu encoder, directing data loss toward less informative artifacts to improve compression while preserving text readability.
PDE Collaborative Enhancement and Compression	1	2017	Historical Document Images	Yagoubi, Serir, & Beghdadi (2017)	Utilizes partial differential equation (PDE) analysis for document enhancement before compression. Collaboratively integrates enhancement with codecs such as JPEG2000 and JPEG-XR to reduce entropy and improve coding efficiency.
Wavelet / Transform (JPEG2000, JPEG-XR, Waveatoms)	2	2016–2017	Document Images (Historical/Manuscript)	Yagoubi et al. (2016, 2017)	Employs wavelet or directional transform techniques (e.g., waveatoms) as core encoding tools. JPEG2000 serves as a benchmark for multi-resolution document compression.
SPIHT (Set Partitioning in Hierarchical Trees)	1	2016	General Images (applicable to documents)	ZainEldin, Elhosseini, & Ali (2016)	Proposes a memory-efficient modification of the SPIHT algorithm. Its DWT and bit-plane structure are relevant for document images due to their binary and high contrast nature.
Lossless Binary Image Codecs (JBIG, JBIG2, JPEG-LS, CALIC, Run Length, Group3/4)	1	2018	Binary / Grayscale Document Images	Sayood (2018)	A comprehensive overview of standard lossless codecs used in document archiving. These formats ensure bitwise integrity, suitable for legal, administrative, or faxed digital documents.
Chain Code + Context Mixing	1	2016	Contour / Binary Shape Images	López-Valdez, Sánchez-	Represents groups of binary contours with a single chain code and compresses them

(Lossless Contour Compression)				Cruz, & Mascorro-Pantoja (2016)	using context mixing. Effective for vector document elements such as glyphs and line drawings.
Machine Learning Compression (AE, VAE, CNN, Transformer, PCA, GAN)	1	2023	General Images (applicable to document domain)	Jamil, Piran, Rahman, & Kwon (2023)	Provides a comprehensive survey of deep learning lossy compression architectures (autoencoder, VAE, GAN, transformer). Highlights the emerging standard JPEG AI and its potential applications to document image compression.

Discussion

Between 2016 and 2018, research on document image compression was primarily dominated by classical transform techniques. The most frequently appearing algorithms included wavelet transform based methods, particularly JPEG2000, SPIHT (Set Partitioning in Hierarchical Trees), and chain code contour representations. These approaches focused on multiresolution decomposition, efficient entropy coding, and contour simplification. Within this period, the DjVu format also appeared as a hybrid method that combined foreground background segmentation with a specialized progressive compression process. DjVu's strength lay in its ability to separate textual layers from background textures, making it particularly effective for handwritten and historical manuscripts.

In addition, lossless binary image codecs such as JBIG, JBIG2, and JPEG-LS were used in document imaging systems that required perfect data preservation, including fax digitization, legal record archiving, and administrative document storage. Together, these findings indicate that the 2016-2018 period was dominated by transform domain methods and standardized codecs emphasizing data fidelity and compression ratio efficiency.

During 2017 to 2019, several studies began to bridge the gap between image enhancement and compression. Notably, the works by Yagoubi et al. (2016, 2017) presented joint enhancement–compression frameworks, which integrated preprocessing steps directly into the encoding process. The implementation used PDE (Partial Differential Equation) analysis to enhance document readability and suppress background noise prior to compression. This collaborative approach improved both the visual quality and compression performance when combined with codecs such as JPEG2000 and JPEG-XR. The integration of enhancement and compression marked a methodological transition, where optimization of document clarity and storage efficiency were treated as a single system rather than two separate stages. This reflects a shift from purely mathematical transforms toward hybrid systems that combine filtering, enhancement, and encoding within one workflow.

From 2019 to 2025, the dominant trend in image compression research reflected also in the document domain shifted toward machine learning approaches. The most significant contribution came from Jamil et al. (2023), who compiled a comprehensive survey of learning lossy image compression methods. Several architectures were identified, including Autoencoders (AE), Variational Autoencoders (VAE), Convolutional Neural Networks (CNN), Generative Adversarial Networks (GAN), and Transformer codecs. These methods rely on learned latent representations rather than predefined transforms, enabling adaptive compression tuned to visual structures within the data. While most of these models were initially trained on natural images, they have high potential for application to document images, particularly for maintaining text sharpness, page structure, and visual readability at low bitrates.

The observed trend between 2019 and 2025 therefore marks the beginning of a data era in compression research, characterized by neural architectures replacing conventional transform coding and by the introduction of hybrid neural codecs such as JPEG AI, which are now being designed for document, medical, and mixed content imagery.

CONCLUSIONS

This study reviewed 56 journal articles from ScienceDirect (2016 to 2025) related to document image compression. Only six papers were found to directly address this topic, revealing that research in this domain remains limited compared to general image compression studies.

The findings show three main development phases:

1. Classical transform methods (2016-2018), including *JPEG2000*, *SPIHT*, *Chain Code*, *JBIG*, *JBIG2*, and *JPEG-LS*
2. Hybrid enhancement compression approaches (2017-2019) such as *DjVu* and *PDE collaborative models*; and
3. Machine Learning frameworks (2019-2025), featuring *Autoencoder*, *VAE*, *GAN*, *Transformer*, and *JPEG AI*.

Overall, the evolution reflects a transition from mathematically designed transforms toward data, adaptive compression methods. Classical techniques remain crucial for standardization, while neural approaches open new opportunities for readability preservation, OCR compatibility, and efficient digital archiving.

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