

Analysis of Deep Learning Method Development for Performance Optimization of Complex Data Classification Models

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ABSTRACT

This study aims to analyze the development of deep learning methods for optimizing complex data classification model performance through a Systematic Literature Review (SLR) approach examining 25 Scopus-indexed scientific articles published between 2024 and 2025. The analysis employs bibliometric techniques using VOSviewer to map keyword networks, temporal trends, and term density patterns. Visualization results identify three primary clusters: (1) LSTM-based classification and intrusion detection systems in cybersecurity applications; (2) CNN optimization and model efficiency for medical imaging and satellite image classification; and (3) artificial intelligence integration with visual classification and evolutionary optimization algorithms. Recent trends demonstrate the dominance of keywords such as "optimization," "effectiveness," and "feature selection," alongside growing interest in hybrid approaches and metaheuristic algorithms. This research provides a comprehensive overview of methodological transformations and application directions of deep learning in complex data classification domains. These findings are expected to serve as strategic references for advancing research and applications in big data-driven artificial intelligence technologies.

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1. Introduction

The last few years have seen a leap in computing technology, which has revolutionized the development of artificial intelligence, and in particular deep learning. Deep learning is a field of machine learning that is a branch of artificial intelligence (AI), and uses multi-layered neural networks to automatically learn feature representations (hierarchies) from large datasets. Its applications are no longer limited to traditional image and speech recognition, but have also expanded to text modeling, bioinformatics, spatial data analysis, and intelligent prediction systems with complex data structures. Deep learning models for classification, known for their powerful ability to detect complex and non-linear patterns in high-dimensional data with complicated and noisy structures, are becoming increasingly popular. Unlike traditional methods such as decision trees, or support vector machines, deep neural networks learn directly from raw data, automatically constructing informative representations as well (LeCun et al., 2015). This capability is ideal for Big Data problems, where many different and unstructured data formats are common.

The evolution of architectures has resulted in a number of high-performance models suitable for optimizing classification performance in many domains. Convolutional

Neural Networks are good at handling spatial data and images (Krizhevsky et al., 2012), while Recurrent Neural Networks and Long Short-Term Memory networks are suitable for sequence data such as text and time-series signals (Hochreiter & Schmidhuber, 1997). Transform-based and BERT-based architectures have revolutionized natural language processing (Vaswani et al., 2017; Devlin et al., 2019). All models are refined by adaptation methods according to the requirements of data complexity and classification tasks. However, implementation issues still persist due to high computational cost, overfitting in the case of small samples, and lack of interpretability of classification results. Modern work attempts to address these issues with optimization techniques such as regularization, fine-tuning, data augmentation, and hyperparameter tuning methods (Goodfellow et al., 2016). These methods have shown significant improvements in accuracy as well as efficiency on various challenging datasets. Zhang et al. (2021) showed that ensemble and hybrid deep learning frameworks outperform single model-based approaches, especially in medical image classification and anomaly detection tasks. Chen et al. (2020) have effectively combined CNN with AM applying it to retinal disease diagnosis to achieve better classification sensitivity. Industrial applications have also been comprehensively developed, such as quality control in manufacturing, predictive maintenance schemes, and autonomous vehicle classification in the industrial era 4.0 (Wang et al., 2022).

As deep learning expands into various industries including healthcare, agriculture, finance, and transportation in Indonesia, its application continues. However, there are infrastructure and expertise constraints that limit its general application. It is essential to closely monitor the progress of deep learning and its optimization potential in a systematic effort for high-quality complex data classification. The analysis further informs national and international research initiatives and data-driven technology development. In this study, Researchers study the evolution of deep learning methods for improving complex data classification performance including advancements in architectures and optimization methods, as well as application trends across industries. This work uses a systematic analysis of indexed scientific literature to map technological progress and observe emerging trends. The results seek to inform a robust understanding of development pathways and barriers and outline strategic recommendations for future research and practice.

2. Methodology

This research methodology uses a Systematic Literature Review (SLR) approach based on bibliometric techniques to analyze trends, directions, and developments in deep learning methods in optimizing the performance of complex data classification models. The data collection process was carried out by selecting 25 scientific articles published between 2021 and 2025 and indexed by Scopus. All selected articles met the inclusion criteria, namely relevance to the topic of deep learning-based classification, the use of modern optimization algorithms or network architectures, and the use of complex data in the form of images, text, or sequential signals. The article search technique used keywords such as "deep learning," "classification," "optimization," "CNN," and "LSTM,". To ensure the objectivity and traceability of the selection process, manual screening of abstracts and full texts was carried out to evaluate the suitability of the topic and context of the study. After the article curation process was completed, bibliometric analysis was carried out using VOSviewer software to map the visualization of keyword networks (networks), temporal trends (overlays), and term densities (densities). The data analysis technique was carried out qualitatively-descriptively with a thematic approach to categorize the tendencies of the methods used, such as the use of CNN, LSTM, transformers, hybrid models, and optimization algorithms such as PSO,

GWO, BWO, and others. The visualization results were used to identify dominant clusters in the literature, the relationship between technical terms, and the emergence of the latest trends in the development of deep learning model architecture and tuning. The author then compiled a discussion based on the structure of the visualization cluster and narratively linked to 25 citations of the articles that had been analyzed to provide an in-depth overview of the current research landscape and potential future research directions in deep learning-based complex data classification.

3. Results

3.1 Visualization Network

VOSviewer's Network Visualization depicts a map of the relationships between keywords in studies related to the development of deep learning methods for optimizing the performance of complex data classification models. This visualization shows three main clusters based on the frequency and strength of the relationship between terms. Each cluster represents a related thematic focus, while also indicating the current research direction in the field of deep learning-based classification.

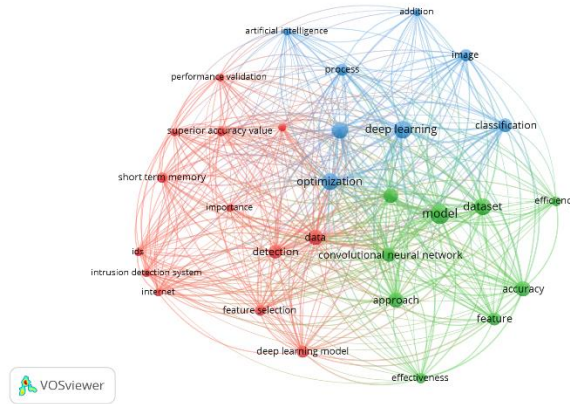


Figure 1. Visualization Network

The first cluster (in red) consists of keywords such as data, detection, feature selection, ids, intrusion detection system, and short-term memory. This cluster shows the research focus on cybersecurity and intrusion detection systems. Some relevant studies include Alkhonaini et al. (2025) who developed a sandpiper optimization model to detect intrusions in IoT systems with 99.59% accuracy, and Alhayan et al. (2025) who used an ensemble learning approach (DBN, GRU, LSTM) to improve IDS performance through parameter optimization. Research by Khosravi et al. (2025) also emphasized the importance of using LSTM and BiLSTM in sequential classification, such as for forest fire detection based on satellite data. In addition, the concept of superior accuracy value and performance validation are the main concerns in measuring the effectiveness of models applied in the context of big data and network-based security systems. The second cluster (in green) includes keywords such as model, dataset, accuracy, efficiency, feature, convolutional neural network, and effectiveness. This cluster represents studies that focus on optimizing the performance of classification models in general, both in terms of accuracy, efficiency, and model structure. A study by Al-Mahdi et al. (2025) that combines genetic algorithm-based feature selection and ensemble deep learning shows a significant increase in the accuracy of heart disease prediction. Meanwhile, Alamgeer et al. (2024) uses Dung Beetle Optimization to improve CNN performance in satellite image classification, and Dai (2024) integrates BiLSTM and

particle swarm optimization for electrical load forecasting. All of these studies highlight the importance of dataset efficiency, model effectiveness, and classification precision in dealing with complex data. The third cluster (in blue) consists of keywords such as deep learning, image, classification, optimization, artificial intelligence, and process. This cluster leads to the development of image classification methods and technical optimization based on artificial intelligence. A study by Li et al. (2025) introduces Hybrid Prior-Net for corneal image quality classification, showing that the integration of visual features and structural optimization can improve classification performance by up to 99%. Another study by Purni & Vedhapriyavadhana (2024) used CNN optimized with the EOSA algorithm for skin cancer classification. In addition, the integration of AI and deep learning in the model optimization process is also seen in the research of Nehzati (2025) which utilizes an evolutionary approach to increase the convergence speed and accuracy of CNN and RNN in large-scale digital data processing. This visualization shows a close relationship between optimization methods, neural network modeling, and image-based or big data classification. The three clusters formed show that research in the field of deep learning for complex data classification is developing towards intelligent security systems, predictive performance optimization, and AI-based visual processing. The multi-model approach and integration of optimization algorithms are the main strategies in increasing the effectiveness of deep learning in various domains.

3.2 Overlay Network

The overlay visualization of VOSviewer illustrates the temporal dynamics of keyword occurrence in studies related to the development of deep learning methods for optimizing the performance of complex data classification models. The color of each node reflects the average year that the keyword appeared in the publications. Blue indicates early occurrence, while yellow indicates newer and emerging keywords. Thus, this visualization helps identify current trends and directions in deep learning-based research.

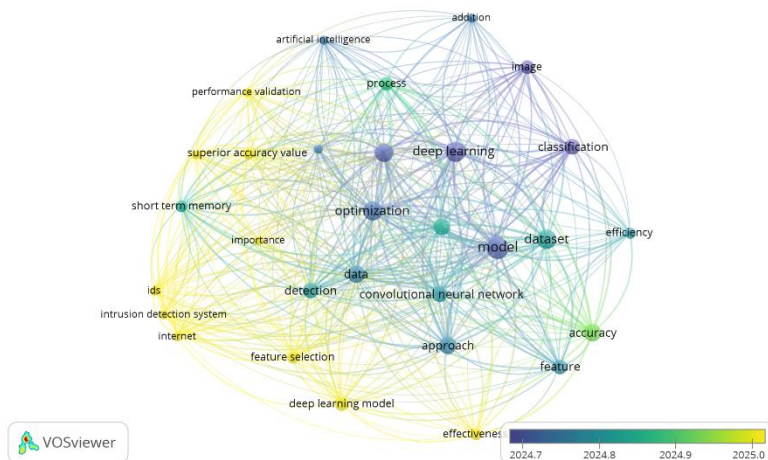


Figure 2. Overlay Network

In the graph, terms such as image, classification, and artificial intelligence are in the blue-purple spectrum, indicating that these topics have long been the initial focus of deep learning-based classification research, especially on visual data. On the other hand, keywords such as ids, superior accuracy value, short-term memory, and feature selection appear in yellow, indicating that themes related to intrusion detection systems, accuracy optimization, and LSTM utilization have recently received intensive attention. The word effectiveness, which is also in the yellow spectrum, indicates that researchers

are now starting to focus more on the real impact and efficiency of the methods developed. In addition, concepts such as optimization, dataset, and convolutional neural network are in the green-green spectrum, indicating consistency and continuity in researchers' interest over the past two years.

Table 1. Frequency of Articles Based on Year of Publication

Year	Frequency	Percentage (%)
2021	0	0%
2022	0	0%
2023	0	0%
2024	6	24%
2025	19	76%
Total	25	100%

This condition is supported by the data in Table 1. Of the total 25 articles reviewed, 76% were published in 2025, while the remaining 24% were published in 2024. There were no relevant publications in 2021 to 2023, indicating that intensive exploration of deep learning for complex data classification is a new trend that has started to grow rapidly in the last two years. This correlation is clearly visible in the overlay visualization, where many dominant keywords are colored yellow, reinforcing that aspects such as intrusion detection, performance validation, and model efficiency are very current topics. Thus, it can be concluded that research on deep learning methods in the context of complex data classification has increased significantly in the last two years. Researchers are now paying more attention to improving the accuracy, effectiveness, and efficiency of models through the integration of algorithmic optimization and exploration of sequential models such as LSTM. The visualization and publication data together indicate a shift in focus from simply developing models to utilizing adaptive, fast, and appropriate models in the context of dynamic and complex data.

3.3 Density Network

Density visualization from VOSviewer is used to show the level of density of keyword occurrences in the literature related to the topic being studied. The brighter the color (yellow) that appears in an area, the higher the frequency of occurrence and its association in the document collection. Conversely, dark blue areas indicate low frequency or rarely formed connections. Thus, density visualization provides a visual overview of the main focus of research and the most frequently used terms together in the field of deep learning for complex data classification.

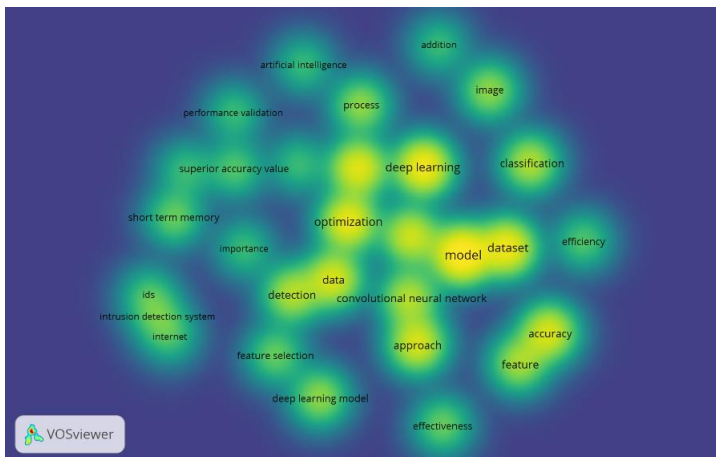


Figure 3. Network Density

In Figure 3, the brightest yellow area is concentrated on keywords such as model, dataset, optimization, and deep learning. This indicates that these terms are central to research development. The words model and dataset are at the center of density because many studies focus on the development of model architectures and the use of various datasets in classification experiments. Meanwhile, optimization is often used in the context of improving model performance, either through parameter tuning, feature selection, or the use of evolutionary algorithms. The presence of deep learning in the dense area confirms that this approach is the main foundation in modern classification systems. Furthermore, quite high density is also seen in keywords such as convolutional neural network, detection, accuracy, and approach. This shows that the use of CNN as the main technique for image or visual data classification is a dominant trend, supported by a focus on detection and accuracy improvement. On the bottom right side, the words accuracy, feature, and effectiveness appear in bright green, indicating that the evaluative aspects of models and feature selection are important concerns in optimizing classification systems. On the other hand, darker areas such as addition, importance, and internet indicate that these terms have a lower frequency in the mapped concept network. Nevertheless, their presence still contributes to shaping the research landscape, especially in the context of implementing internet-based systems and interpreting the meaning of features in data. This visualization shows that the study of deep learning methods for complex data classification is dominated by discussions of models, datasets, and optimization processes, with high attention to accuracy and performance effectiveness. The high density at strategic points illustrates the focus of research on efforts to improve model architecture and performance in responding to data diversity and complexity.

4. Discussion

4.1 The Evolution of Deep Learning in Complex Data Classification

The development of deep learning in complex data classification has shown sharp acceleration in the last two years. This is reflected in the overlay visualization and frequency table, which show that 76% of the articles analyzed were published in 2025. Recent research focuses on exploring neural network models such as CNN, BiLSTM, RNN, to hybrid architectures to handle various types of data: from medical images (Li et al., 2025; Alamri et al., 2025), satellite data (Alamgeer et al., 2024), to Arabic text (Alzaidi et al., 2025). Alkhonaini et al. (2025) combined CNN with stacked autoencoder in an IoT security system using blockchain and sandpiper optimization. This model achieved 99.59% accuracy for intrusion detection, marking a strong synergy between network architecture and optimization algorithm. Meanwhile, Nehzati (2025) developed an evolutionary neural network-based approach to improve the performance of CNN and RNN on a big digital data scale. These studies illustrate a new orientation towards model efficiency, generalization, and adaptability in dynamic data environments. Purni and Vedhapriyavadhana (2024) demonstrated the effectiveness of using the Ebola Optimization Search Algorithm (EOSA) on CNN for multiclass skin cancer classification, while Muduli et al. (2025) utilized DenseNet and explainable AI techniques in leukemia detection, confirming that visual classification is still the dominant domain for deep learning applications.

4.2 Model Optimization Through Metaheuristics and Evolutionary Algorithms

Hyperparameter optimization has become an important focus in improving the performance of deep learning classification. Many studies have utilized bio-inspired and metaheuristic algorithms such as Particle Swarm Optimization (Dai, 2024), Dung Beetle Optimization (Alamgeer et al., 2024), and Secretary Bird Optimization (Assiri & Selim, 2025). The goal of these approaches is to find the optimal combination of

architecture and training parameters that yield high accuracy with efficient computational load. Al-Mahdi et al. (2025) used Genetic Algorithm and Tunicate Swarm Algorithm in heart disease prediction, forming a deep learning ensemble model with high efficiency. As a result, this model achieved 97.5% accuracy with minimal memory and CPU consumption. In the realm of cybersecurity, Alhayan et al. (2025) integrated LSTM, GRU, and DBN in an ensemble system for intrusion detection with the help of Improved Whale Optimization (IBWO), resulting in an accuracy of 99.77%. Deep learning models are not only optimized for accuracy, but also for openness of interpretation. In this context, Hassan et al. (2025) used the LIME method to explain the results of plankton classification visually and analytically. The combination of feature fusion and Whale Optimization Algorithm (WOA) in this study increased the accuracy to 98.79%, making transparency an added value in AI-based classification.

4.3 Application Domain Diversification and Model Generalization

Deep learning methods are now applied across domains, demonstrating their generality and flexibility in handling various types of complex data. In the energy sector, Dai (2024) and Mohseni-Gharyehsafa et al. (2025) developed models for electrical load prediction and building retrofit optimization using CNN, BiLSTM, and Gaussian Process. This approach presents concrete solutions for energy efficiency and smart city planning. In the health context, glaucoma (Muduli et al., 2025) and brain tumor detection (Alamri et al., 2025) were developed using a combination of CNN with optimizers such as Gray Wolf and Siberian Tiger Optimization. This shows that the success of the classification depends not only on the choice of architecture, but also on the right optimization strategy and data pre-processing. The application of deep learning is also found in the agricultural sector (Antony & Kumar, 2024), gesture recognition for the deaf (Assiri & Selim, 2025), and even the classification of medicinal plants (Bouakkaz et al., 2025). This emphasizes that complex data classification is not limited to medical images or cybersecurity alone, but has also penetrated the education sector (Zheng, 2025) and culture such as the prediction of the constitution of Chinese medicine (Zhang et al., 2024).

4.4 Future Research Directions and Technological Implications

Density analysis and overlay visualization show that keywords such as “model”, “dataset”, and “optimization” have high density and appear in recent articles. This indicates a shift in focus from basic model development to optimizing efficiency, accuracy, and interpretability. Keywords such as “short-term memory”, “feature selection”, and “effectiveness” that only appeared in 2025 reflect a new trend in combining sequential architectures and algorithm-based feature selection techniques. With the dominance of articles in 2025 (76% of the total), it is clear that deep learning research in complex data classification is still in the rapid exploration phase. Studies by Muduli et al. (2025), Alkhonaini et al. (2025), and Li et al. (2025) indicate a strong push towards the application of deep learning in real-world contexts, such as telemedicine-based healthcare and cloud security systems. On the other hand, studies such as Farhat et al. (2025) who developed YOLOv8 for pedestrian detection show that real-time aspects and inference efficiency are now the main focus. From all the articles analyzed, it can be concluded that the integration of deep learning with optimization algorithms has made a significant contribution to improving classification performance. The technological implications of this trend include the development of automated medical diagnosis systems, real-time cyber threat detection, UAV and satellite-based image classification, and NLP-based learning system personalization.

5. Conclusion and Recommendations

Based on the results of the analysis of 25 scientific articles, it was found that the development of deep learning methods in complex data classification has shown a significant surge in the last two years. The dominance of CNN, LSTM models, and hybrid approaches combined with optimization algorithms such as PSO, Dung Beetle Optimization, and IBWO shows that the current research direction focuses on the efficiency, accuracy, and generalization capabilities of models in various data contexts, ranging from medical images, IoT security systems, to electrical load prediction. Network and density visualizations show that models, datasets, and optimization processes are the main nodes in the development of deep learning-based classification.

The implications of the results of this study include accelerating innovation in automated medical diagnostic systems, developing real-time cyber threat detection systems, and visual classification based on satellite and UAV imagery. In addition, the emergence of explainable AI approaches and interpretable models such as LIME indicates an effort to address the need for transparency in the application of deep learning in the public sector. The study also shows a broad diversification of applications to the education, agriculture, energy, and cultural sectors, reflecting the flexibility of deep learning models in addressing complex data challenges.

Based on these findings, it is suggested that future research focus on three main directions: (1) development of lightweight and efficient architectures for deployment on edge devices; (2) exploration of the combination of deep learning with bio-inspired algorithms to improve training efficiency; and (3) integration of interpretable models to support wider adoption in critical sectors such as healthcare and security. Thus, an adaptive, efficient, and transparent deep learning approach is expected to be the backbone of an intelligent classification system that is responsive to future data dynamics.

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