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Performance and Challenges of Deep Learning-Based Face Recognition Systems: A Systematic Review

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ABSTRACT

This research is motivated by the rapid development of Artificial Intelligence (AI) and the increasing use of face recognition systems in various fields such as security and education. Face recognition, as part of computer vision, enables systems to identify individuals based on unique facial characteristics. This study aims to review the application of Deep Learning methods in face recognition systems, with a focus on commonly used algorithms, model performance, and existing challenges. This study employs a systematic literature review approach by analyzing various relevant scientific publications. Data were collected from reliable academic sources and analyzed qualitatively to identify research trends, methods, and gaps. The results of the study indicate that Convolutional Neural Network (CNN) and its variants, such as FaceNet and VGG-Face, are the most widely used methods and demonstrate high performance in terms of accuracy and reliability. However, several challenges remain, including the need for large-scale datasets, variations in image conditions, and high computational complexity. This study contributes by providing a comprehensive synthesis of Deep Learning applications in face recognition and identifying research gaps and opportunities for future development to improve system effectiveness and efficiency.

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Introduction

Deep Learning has become one of the most widely used approaches in computer vision, particularly in face recognition systems. Face recognition is a biometric technology that enables systems to identify or verify individuals based on their facial characteristics. Compared to conventional biometric methods, face recognition provides a more efficient and non-contact identification process, making it suitable for applications such as security systems, surveillance, attendance systems, and access control [1], [2].

Early face recognition systems mainly relied on traditional machine learning techniques and handcrafted feature extraction methods. However, these approaches often experience limitations in handling variations such as illumination, facial expressions, pose changes, and image quality [3], [4]. As face recognition applications continue to expand in real-world environments, more adaptive and robust approaches are required.

The advancement of Deep Learning has significantly improved the accuracy and reliability of face recognition systems. Among various Deep Learning architectures, Convolutional Neural Network (CNN) has become the dominant method due to its capability to automatically extract hierarchical facial features from image data [5], [2]. In addition, advanced architectures such as FaceNet, ResNet, and Deep CNN have demonstrated strong performance in large-scale face recognition tasks [6], [7], [8].

Recent studies have explored various approaches to improve face recognition under challenging conditions, including masked face recognition and face anti-spoofing detection [9],[10],[11]. Despite the promising performance, several challenges remain, such as the need for large-scale datasets, high computational complexity, variations in environmental conditions, and privacy concerns [1], [3]. These challenges indicate that further research is still needed to improve the effectiveness and robustness of Deep Learning-based face recognition systems. Given the rapid development in this field, a comprehensive literature review is necessary to identify research trends, commonly used algorithms, model performance, and existing challenges. Therefore, this study aims to review the implementation of Deep Learning methods in face recognition systems by analyzing relevant studies published between 2022 and 2025.

Materials and Methods

This study employs a Systematic Literature Review (SLR) approach to examine various studies related to the application of Deep Learning-based face recognition systems [5], [11]. This method is chosen because it provides a more structured, systematic, and transparent process for reviewing the literature. In this study, the SLR process follows the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). This approach allows the processes of identification, screening, and analysis of the literature to be carried out in a step-by-step manner, resulting in more valid and reliable findings [1]. Through this method, the study aims to identify trends in the use of Deep Learning algorithms, evaluate the performance of models used in previous studies, and identify challenges faced in the implementation of Deep Learning-based systems.

A. Selection Criteria and Research Framework

To ensure a systematic and relevant selection of literature, this study adopts the PICOC (Population, Intervention, Comparison, Outcome, Context) framework in defining the selection criteria [5]. The PICOC framework applied in this study is presented in Table 1.

Table 1. Methodological Framework for Research Questions

Element	Description
Population (P)	Studies that discuss face recognition systems as part of biometric technology.
Intervention (I)	The application of Deep Learning algorithms used in the face recognition process.
Comparison (C)	Comparison of various Deep Learning algorithms or methods used in face recognition research.
Outcome (O)	Research outcomes in the form of system performance, such as accuracy, processing speed, and the system's ability to recognize faces.
Context (C)	Studies that examine the application of Deep Learning in face recognition systems across various domains, such as security, attendance systems, and biometric identification.

To clarify the focus of this study, three research questions (RQs) were formulated as the basis for the analysis process. First, this study identifies the most commonly used Deep Learning algorithms in face recognition systems (RQ1). Second, it evaluates the performance of Deep Learning algorithms based on the metrics reported in previous studies (RQ2). Third, by analyzing the limitations of existing studies, this research identifies the challenges in implementing Deep Learning for face recognition systems, as well as potential future research directions (RQ3).

Furthermore, to ensure the quality and relevance of the study, only articles that meet the inclusion criteria are considered. These include empirical studies published in scientific journals or conference proceedings, written in Indonesian or English, and available in full-text. Conversely, articles are excluded if they are not relevant to the topic, lack full-text access, are non-empirical in nature, or fall outside the defined study period.

Table 2. Literature Selection Criteria

Criteria	Inclusion (In Scope)	Exclusion (Out of Scope)
Type of Study	Empirical studies published in journals or conference proceedings related to Face Recognition using Deep Learning	Articles published outside scientific journals or proceedings
Language	Indonesian or English	Other languages
Topic	Deep Learning for Face Recognition systems	Not related to Deep Learning or Face Recognition
Year	Published between 2022–2026	Published outside the specified period
Access	Full-text available	Full-text not available (abstract only)
Output	Includes clear methodology and performance evaluation	Does not include clear methods or results

B. Literature Search Strategy

The literature search strategy was conducted to obtain research articles relevant to the topic of Deep Learning in face recognition systems. The search process was carried out using several academic databases, including Google Scholar, Garuda, and other scientific journal sources. In this process, several keywords related to the research topic were used, such as "Deep Learning", "Face Recognition", and "*Pengenalan Wajah*". These keywords were applied both individually and in combination to ensure comprehensive and relevant search results. This strategy was designed to collect literature that aligns with the objectives of the study.

C. Selection Process

After the literature search was completed, the next step was the article selection process. This process was conducted through several stages. First, all retrieved articles were identified and compiled from the search results. Second, the articles were screened based on their titles and abstracts to determine their relevance to the research topic. Third, a full-text review was performed to ensure that the articles met the predefined inclusion criteria. Finally, only articles that satisfied all criteria were selected for further analysis. Through this process, a set of relevant research articles was obtained and used for the literature review on the implementation of Deep Learning in face recognition systems.

D. Data Extraction and Synthesis

Data extraction is the process of collecting important information from each selected research article. This process aims to gather relevant data to facilitate the analysis of previous studies. In this study, data extraction was carried out by identifying key information from each article, including the authors and publication year, research title, methods or Deep Learning algorithms used, and the results obtained. The collected data were then organized into a table of previous studies to enable easier analysis and comparison across different research works. Through this process, the study provides an overview of the methods used and the results achieved in the implementation of Deep Learning for face recognition systems.

Data synthesis is the process of combining and analyzing the extracted data from various studies. This step aims to provide a more comprehensive understanding of the development of research related to Deep Learning in face recognition systems. In this study, data synthesis was conducted by grouping the studies based on the methods or algorithms used,

followed by comparing the results reported in different literature sources. In addition, the analysis includes identifying the strengths and limitations of each method, as well as examining the overall research trends in this field.

The results of the data synthesis are then used to support the discussion of research developments, commonly used methods, and the performance of Deep Learning algorithms in face recognition systems. Therefore, this study is expected to provide a clearer understanding of the advancement of Deep Learning-based face recognition technology based on previous research.

Results

This section presents a systematic review of the literature related to the application of Deep Learning in face recognition systems, with the main findings summarized in the results table (Table 3). Through the data synthesis conducted, this section aims to address the research questions (RQs) formulated in the previous stage.

RQ1: Deep Learning Algorithms in Face Recognition

Based on the literature review, the use of Deep Learning algorithms in face recognition has shown significant growth in recent years. The most commonly applied algorithms include Convolutional Neural Network (CNN) and its variants, such as DeepFace, FaceNet, and VGG-Face. These models dominate face recognition research [5], [2] due to their ability to automatically extract and learn complex facial features from image data. CNN-based models are widely used because they can capture spatial hierarchies in facial images, enabling more accurate feature representation. In addition, several studies have explored advanced architectures such as ResNet and Inception-based models to further improve recognition performance. Besides single-model approaches, some studies have also proposed hybrid methods that combine Deep Learning with traditional Machine Learning algorithms. These hybrid approaches aim to enhance feature extraction and classification performance, resulting in improved accuracy in certain scenarios.

RQ2: Performance of Deep Learning Algorithms

The performance of Deep Learning algorithms in face recognition is generally evaluated using metrics such as accuracy, precision, recall, and F1-score. Based on the literature analysis, most Deep Learning models demonstrate high performance, with accuracy often exceeding 90% [5], [9] in controlled environments. CNN-based models tend to achieve strong performance in recognizing facial patterns, while advanced architectures such as FaceNet show improved results in large-scale and real-world datasets. Additionally, models trained on large datasets with proper preprocessing techniques generally produce more robust and reliable results. However, performance variations across studies are still observed. These differences are influenced by several factors, including dataset size, image quality, variations in lighting and pose, and the preprocessing techniques applied. Therefore, model performance is not solely determined by the algorithm itself, but also by the quality and diversity of the data used.

RQ3: Challenges in Applying Deep Learning for Face Recognition

Despite the promising performance of Deep Learning-based face recognition systems, several challenges remain. One of the main challenges is the requirement for large-scale labeled datasets to train high-performing models. Collecting and annotating such datasets can be time-consuming and resource-intensive [9], [11]. Another challenge is the variation in real-world conditions, such as changes in lighting, facial expressions, occlusions (e.g., masks), and pose variations. These factors can significantly affect recognition accuracy, especially in uncontrolled environments.

In addition, high computational cost is a major concern, particularly for complex Deep Learning models, which require significant processing power and time for training and deployment. This limitation can hinder real-time implementation in resource-constrained systems. Furthermore, issues related to privacy and data security have become increasingly important, as face recognition systems involve sensitive personal data. Ethical concerns regarding data usage and system transparency also need to be addressed. Considering these challenges, further research is needed to improve the effectiveness and efficiency of Deep Learning models, particularly in developing more robust algorithms, optimizing computational performance, and addressing privacy concerns in face recognition systems. The summary of the selected studies can be seen in Table 3.

Table 3. Summary of Deep Learning-Based Face Recognition Systems literature

Study	Database	Focus	Model / Architecture	Metrics	Dataset	Key Findings
Saragih et al. [1]	Garuda / SINTA	Face Recognition	CNN	Accuracy	Local Face Dataset	CNN effectively recognizes facial patterns in controlled environments
Pratama et al. [2]	Garuda / SINTA	Attendance System	CNN	Accuracy	Student Face Dataset	Face recognition improves attendance automation
Wibowo et al. [3]	Garuda / SINTA	Real-Time Recognition	CNN + OpenCV	Accuracy, Speed	Webcam Dataset	Real-time recognition depends on lighting conditions
Putra et al. [4]	Garuda / SINTA	Biometric Identification	Deep Learning	Accuracy	Local Dataset	Deep Learning enhances biometric identification performance

Study	Database	Focus	Model / Architecture	Metrics	Dataset	Key Findings
Rahman et al. [5]	Garuda / SINTA	Security System	CNN	Accuracy	Real-world Dataset	CNN performs well but affected by occlusion
Hidayat et al. [6]	Garuda / SINTA	Smart Attendance	FaceNet	Accuracy	Campus Dataset	FaceNet improves recognition accuracy compared to conventional CNN
Saputra et al. [7]	Garuda / SINTA	Face Detection	CNN	Precision, Recall	Image Dataset	CNN provides stable facial feature extraction
Maulana et al. [8]	Garuda / SINTA	Face Recognition	ResNet	Accuracy	Face Image Dataset	ResNet improves deep feature learning performance
Kurniawan et al. [9]	Garuda / SINTA	Surveillance System	CNN + Transfer Learning	Accuracy	CCTV Dataset	Transfer learning accelerates training process
Ananda et al. [10]	Garuda / SINTA	Face Authentication	Deep CNN	Accuracy, F1-score	Local Authentication Dataset	Deep CNN improves authentication reliability
Liu et al. [11]	Scopus	Face Recognition	Deep Learning	Accuracy	Various Datasets	DL improves recognition performance with limited samples
Chen et al. [12]	Scopus	Face Recognition	CNN, FaceNet	Accuracy	LFW, CASIA	CNN-based methods dominate modern face recognition
Jing et al. [13]	Scopus	3D Face Recognition	3D CNN	Accuracy	FRGC	3D approaches improve robustness against pose variation
Yu et al. [14]	Scopus	Face Anti-Spoofing	CNN-based DL	Accuracy, Recall	CASIA-FASD	DL improves anti-spoofing performance
Alturki et al. [15]	Scopus	Masked Face Recognition	CNN, Transfer Learning	Accuracy	RMFD	Masked face recognition remains challenging

Discussion

The findings of this study highlight the rapid development of Deep Learning techniques in face recognition systems. Based on the literature reviewed, Convolutional Neural Network (CNN) remains the most dominant approach due to its strong capability in extracting hierarchical features from facial images. Various CNN-based architectures, including FaceNet, ResNet, and Deep CNN, have been widely adopted and show significant improvements in recognition accuracy. In addition, several studies have explored hybrid approaches and transfer learning techniques to enhance model performance and reduce training complexity.

In terms of performance (RQ2), most studies report high accuracy levels, often exceeding 90%, particularly in controlled environments. However, performance tends to decrease in real-world scenarios where variations such as lighting conditions, pose differences, and occlusions are present. This indicates that while Deep Learning models are highly effective, their robustness is still dependent on data quality, preprocessing techniques, and dataset diversity.

Regarding challenges (RQ3), several key issues have been identified. The requirement for large-scale labeled datasets remains a major limitation, as collecting and annotating such data is both time-consuming and resource-intensive. Additionally, variations in real-world conditions, including masked faces and environmental changes, significantly impact recognition performance. High computational costs also pose challenges for real-time implementation, especially in systems with limited resources. Furthermore, privacy and data security concerns are increasingly important, given that face recognition systems involve sensitive personal information. Overall, the results indicate that although Deep Learning has significantly advanced face recognition technology, further research is still needed to improve model generalization, efficiency, and ethical considerations in practical applications.

Conclusions

This study presents a systematic literature review on the application of Deep Learning in face recognition systems. The results show that Deep Learning algorithms, particularly CNN and its variants, have become the most widely used approaches due to their ability to automatically extract complex facial features and achieve high recognition accuracy. In terms of performance, most models demonstrate strong results, especially in controlled environments. However, performance variations still occur depending on dataset characteristics, preprocessing methods, and environmental conditions. This indicates that model performance is influenced not only by the algorithm but also by the quality and diversity of the data used. Despite the promising results, several challenges remain, including the need for large-scale datasets, high computational requirements, sensitivity to real-world variations, and concerns related to privacy and data security. These challenges highlight the need for further research to develop more robust, efficient, and secure face recognition systems. Future research directions may include improving model generalization in unconstrained environments, optimizing computational efficiency for real-time applications, and addressing ethical issues related to data privacy and system transparency.

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