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COMPARATIVE ANALYSIS OF DEEP LEARNING ALGORITHMS FOR AUTOMATED SKIN DISEASE DIAGNOSIS FROM DERMOSCOPIC IMAGES



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Annotatsiya. Dermatoskopik tasvirlar asosida teri kasalliklarini avtomatik tasniflash uchun CNN, ResNet-50 va EfficientNet-B4 arxitekturalarining qiyosiy tahlili amalga oshirildi. Tadqiqot HAM10000 ma'lumotlar to'plamidagi 10 015 ta tasvir va 7 ta nozologik sinf asosida bajarildi. Natijalar aniqlik, sezgirlik, spetsifiklik, F1-score, AUC-ROC, inferens vaqti va xotira sarfi ko'rsatkichlari bo'yicha baholandi. EfficientNet-B4 modeli 93,71 % aniqlik va 0,978 AUC-ROC ko'rsatkichi bilan eng yuqori natijani namoyon etdi. Olingan natijalar mazkur arxitekturaning klinik qarorlarni qo'llab-quvvatlash tizimlarida yuqori samaradorlikka ega ekanligini ko'rsatdi.

Kalit so'zlar: chuqur o'qitish; teri kasalliklari diagnostikasi; convolutional neural network (CNN); ResNet; EfficientNet; dermatoskopiya; HAM10000; tibbiy tasvirlar tahlili; transfer learning; AUC-ROC.

Аннотация. Проведен сравнительный анализ архитектур CNN, ResNet-50 и EfficientNet-B4 для автоматической классификации кожных заболеваний по дерматоскопическим изображениям. Исследование выполнено на наборе данных HAM10000, включающем 10 015 изображений по семи нозологическим классам. Оценка моделей осуществлялась по показателям точности, чувствительности, специфичности, F1-score, AUC-ROC, времени инференса и объему используемой памяти. Наилучшие результаты продемонстрировала архитектура EfficientNet-B4: точность составила 93,71 %, а значение AUC-ROC — 0,978. Полученные результаты подтверждают перспективность применения данной архитектуры в системах поддержки принятия клинических решений.

Ключевые слова: глубокое обучение; диагностика кожных заболеваний; сверточная нейронная сеть (CNN); ResNet; EfficientNet; дерматоскопия; HAM10000; анализ медицинских изображений; transfer learning; AUC-ROC.

Abstract. A comparative analysis of CNN, ResNet-50, and EfficientNet-B4 architectures for automated skin disease classification from dermoscopic images was conducted. The study was performed using the HAM10000 dataset comprising 10,015 images across seven nosological classes. Model performance was evaluated using accuracy, sensitivity, specificity, F1-score, AUC-ROC, inference time, and memory footprint. EfficientNet-B4 demonstrated the best performance, achieving 93.71 % accuracy and an AUC-ROC of 0.978. The obtained results indicate the potential of this architecture for integration into clinical decision-support systems.

Keywords: deep learning; skin disease diagnosis; convolutional neural network (CNN); ResNet; EfficientNet; dermoscopy; HAM10000; medical image analysis; transfer learning; AUC-ROC.

INTRODUCTION

Skin diseases represent one of the most prevalent categories of human pathology. According to international medical statistics, hundreds of millions of people are affected by skin disorders at any given time. Early and accurate detection of melanoma is clinically important because survival rates are substantially higher when the disease is diagnosed at an early stage [1].

Over the past decade, deep learning methods, particularly convolutional neural networks, have demonstrated strong performance in medical image analysis tasks. In dermatology, automated image-based diagnosis has become an important approach for reducing diagnostic delays and supporting physicians in settings where access to specialists is limited [2; 3].

The object of this study is the automated classification of dermoscopic images. The subject of the study is the diagnostic performance of CNN, ResNet-50, and EfficientNet-B4 architectures under conditions of class imbalance, varying input resolutions, and computational constraints.

The aim of the research is to compare three representative deep learning architectures for multi-class skin lesion classification and to identify the model that provides the most appropriate balance between diagnostic accuracy and computational cost. The research tasks include training and fine-tuning the selected models, comparing their performance using clinically relevant metrics, analysing computational trade-offs, and developing practical recommendations for clinical deployment.

LITERATURE REVIEW

The application of deep learning to dermoscopic image analysis has grown substantially since 2017. Esteva et al. demonstrated that a deep CNN trained on a large clinical image dataset could classify skin cancer at a level comparable to that of qualified dermatologists, thereby stimulating further research in AI-based dermatology [3].

Codella et al. introduced the HAM10000 dataset, which subsequently became a widely used benchmark for skin lesion classification. Their study established an important baseline for seven-class dermoscopic classification and demonstrated the complexity of the task due to the visual similarity among different lesion types [4].

He et al. developed the ResNet architecture with residual connections, which addressed the gradient vanishing problem and enabled the effective training of deeper neural networks [5]. In medical image classification, ResNet-50 is widely used because it provides stable transfer learning capabilities and relatively high diagnostic accuracy [6].

Tan and Le proposed EfficientNet, an architecture based on the compound scaling of network depth, width, and resolution. This family of models achieves high accuracy while requiring fewer parameters than many competing architectures [7]. Subsequent studies on skin lesion classification also reported the effectiveness of EfficientNet variants in balancing diagnostic accuracy and computational efficiency [8].

Unlike earlier studies that focused on a single architecture, the present study compares foundational, residual, and compound-scaled architectures within a unified experimental framework. Furthermore, the models are evaluated not only in terms of diagnostic performance but also with respect to inference time, memory footprint, and deployment feasibility.

RESEARCH METHODOLOGY

The research methodology is based on experimental comparison, statistical evaluation, and computational efficiency analysis. The HAM10000 dataset was used as the empirical basis of the study. It contains 10,015 dermoscopic images representing seven disease categories, including melanocytic nevi, melanoma, benign keratosis, basal cell carcinoma, actinic keratosis, vascular lesions, and dermatofibroma [4].

All images were preprocessed and resized according to the requirements of each model: 224×224 pixels for the baseline CNN and ResNet-50, and 380×380 pixels for EfficientNet-B4. A stratified 70/15/15 split was applied to preserve class proportions across the training, validation, and test subsets.

To address class imbalance, geometric transformations, colour-space augmentation, synthetic image generation for minority classes, and weighted random sampling were employed. Transfer learning was applied to ResNet-50 and EfficientNet-B4 using ImageNet pre-trained weights, whereas the baseline CNN was trained from random initialization.

Model performance was evaluated using accuracy, recall (sensitivity), specificity, precision, F1-score, AUC-ROC, inference time, model size, training time, FLOPs, and GPU memory consumption. The statistical significance of differences between models was assessed using McNemar's test at a significance level of $p < 0.05$ (Tables 1 and 2).

Table 1. Composition and Class Distribution of the HAM10000 Dataset¹

No.	Disease Category	Code	Samples (n)	Share (%)	Verification Method
1	Melanocytic nevi	nv	6,705	66.95%	Histopathology
2	Melanoma	mel	1,113	11.11%	Histopathology
3	Benign keratosis	bkl	1,099	10.97%	Histopathology
4	Basal cell carcinoma	bcc	514	5.13%	Expert consensus
5	Actinic keratosis	akiec	327	3.27%	Confocal microscopy
6	Vascular lesions	vasc	142	1.42%	Follow-up
7	Dermatofibroma	df	115	1.15%	Follow-up
Total	—	—	10,015	100%	—

Table 2. Hyperparameter Configuration of the Models²

Hyperparameter	Baseline CNN	ResNet-50	EfficientNet-B4
Input resolution	224 × 224	224 × 224	380 × 380
Batch size	32	32	16
Initial learning rate	1×10^{-3}	1×10^{-4}	1×10^{-4}
LR scheduler	ReduceOnPlateau	Cosine annealing	Cosine annealing
Optimizer	Adam ($\beta_1=0.9$)	Adam ($\beta_1=0.9$)	Adam ($\beta_1=0.9$)
L2 regularization	1×10^{-4}	1×10^{-4}	5×10^{-5}
Freeze epochs	N/A	20	20
Fine-tune epochs	80	60	60
Dropout	0.50	0.40 / 0.30	0.40
Loss function	Focal Loss ($\gamma=2$)	Focal Loss ($\gamma=2$)	Focal Loss ($\gamma=2$)
Pre-trained weights	None	ImageNet	ImageNet
Total parameters	8.4 M	25.6 M	19.3 M

ANALYSIS AND RESULTS

The comparative evaluation showed that EfficientNet-B4 achieved the highest diagnostic performance across all predictive metrics. Its accuracy reached 93.71 %, whereas ResNet-50 achieved 91.24 % and the baseline CNN achieved 87.43 %. The AUC-ROC value also confirmed the superiority of EfficientNet-B4, reaching 0.978 compared with 0.961 for ResNet-50 and 0.934 for the baseline CNN.

The results demonstrate that compound scaling improves the extraction of multi-scale dermoscopic features. EfficientNet-B4 achieved a 6.28-percentage-point improvement over the baseline CNN and a 2.47-percentage-point improvement over ResNet-50. The differences were statistically significant according to McNemar's test ($p < 0.01$) (Table 3).

Table 3. Comparative Evaluation of Model Performance on the HAM10000 Test Dataset³

Metric	Baseline CNN	ResNet-50	EfficientNet-B4
Accuracy (%)	87.43 ± 0.82	91.24 ± 0.61	93.71 ± 0.48
Recall / Sensitivity (%)	84.21 ± 1.14	89.53 ± 0.87	92.18 ± 0.72
Specificity (%)	89.67 ± 0.93	92.84 ± 0.71	95.12 ± 0.59
Precision (%)	85.38 ± 1.21	90.17 ± 0.95	92.64 ± 0.81
F1-Score (%)	84.79 ± 1.08	89.84 ± 0.79	92.41 ± 0.65
AUC-ROC	0.934 ± 0.009	0.961 ± 0.006	0.978 ± 0.004
Inference time – GPU (ms/img)	12.4 ± 0.8	28.7 ± 1.2	45.3 ± 2.1

¹ Source: Compiled by the authors based on the HAM10000 benchmark dataset.

² Source: Developed by the authors based on the experimental configuration.

³ Source: Authors' calculations.

Metric	Baseline CNN	ResNet-50	EfficientNet-B4
Inference time – CPU (ms/img)	48.2	112.4	183.7
Model size (MB)	32.1	98.4	74.6
Training time (hours)	4.2	7.8	11.4
FLOPs (GFLOPs)	1.8	4.1	3.6
GPU memory (GB)	3.2	5.8	6.4

Per-class analysis indicates that all three models performed best on the majority class, melanocytic nevi, and demonstrated reduced performance on minority classes such as actinic keratosis, vascular lesions, and dermatofibroma. This finding confirms that class imbalance remains one of the key methodological challenges in automated dermatological diagnosis.

The most important clinical improvement was observed in melanoma classification. EfficientNet-B4 achieved an F1-score of 89.4 % for melanoma, compared with 85.6 % for ResNet-50 and 78.3 % for the baseline CNN. Since melanoma detection is associated with a high clinical risk, this improvement has significant practical value for screening and clinical decision support (Table 4).

Table 4. F1-Score Performance by Disease Class on the Test Dataset (%)⁴

Disease Class	n (test)	CNN F1 (%)	ResNet-50 F1 (%)	EfficientNet-B4 F1 (%)
Melanocytic nevi (nv)	1,006	92.4	94.8	96.2
Melanoma (mel)	167	78.3	85.6	89.4
Benign keratosis (bkl)	165	81.7	87.2	90.8
Basal cell carcinoma (bcc)	77	75.4	83.1	87.6
Actinic keratosis (akiec)	49	69.2	78.4	83.7
Vascular lesions (vasc)	21	71.8	80.2	86.3
Dermatofibroma (df)	18	68.5	76.9	82.1
Macro-average	1,503	76.76	83.74	87.44

Convergence analysis showed that EfficientNet-B4 reached the 90 % validation accuracy threshold at epoch 28, ResNet-50 at epoch 34, and the baseline CNN at epoch 52. This indicates that pre-trained and compound-scaled architectures converge faster and more stably than models trained from scratch.

Confusion matrix analysis revealed that most EfficientNet-B4 classification errors occurred between visually similar classes, particularly melanoma and melanocytic nevi, as well as melanoma and benign keratosis. Such errors are expected in clinical imaging because these lesion types may exhibit overlapping morphological characteristics (Table 5).

Table 5. Statistical Significance Results for Pairwise Model Comparisons (McNemar Test)⁵

Criterion / Metric	CNN vs ResNet-50	CNN vs EfficientNet	ResNet-50 vs EfficientNet
McNemar χ^2	18.42	31.67	9.84
p-value	< 0.001	< 0.001	< 0.01
Cohen's Kappa (κ)	0.712 vs 0.781	0.712 vs 0.831	0.781 vs 0.831

CONCLUSIONS AND RECOMMENDATIONS

EfficientNet-B4 achieved the highest diagnostic accuracy (93.71 %), AUC-ROC (0.978), and F1-score (92.41 %), while requiring fewer parameters than ResNet-50. This finding confirms the practical effectiveness of compound scaling for dermoscopic image classification.

ResNet-50 provides an optimal balance between diagnostic accuracy and computational cost. It is suitable for clinical decision-support systems where moderate hardware resources are available and stable transfer learning is required.

⁴ Source: Authors' calculations.

⁵ Source: Authors' calculations.

The baseline CNN exhibits the shortest inference time and can be effectively used for high-throughput or edge-screening applications. However, its lower performance on minority classes limits its applicability in high-stakes diagnostic scenarios.

Class imbalance remains a significant challenge in automated skin lesion classification. Future research should focus on few-shot learning, contrastive learning, and generative augmentation techniques to improve the recognition of rare classes.

For clinical deployment, EfficientNet-B4 is recommended for high-risk melanoma detection, ResNet-50 for balanced diagnostic systems, and lightweight CNN or EfficientNet variants for mobile and hardware-constrained environments.

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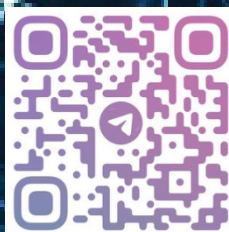
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