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Application of deep learning methods for automated analysis of retinal structures in ophthalmology

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ABSTRACT

This article examines a current area of research in the field of ophthalmology the use of deep learning methods for automated analysis of retinal structures. This work explores the use of deep learning methods such as EfficientNet and DenseNet for the automated analysis of retinal structures in ophthalmology. EfficientNet, originally proposed to balance between accuracy and computational efficiency, and DenseNet, based on dense connections between layers, are considered as tools for identifying and classifying retina features. Automated analysis includes identifying pathologies, assessing the degree of their development and, possibly, diagnosing various eye diseases. Experiments are performed on a dataset containing a variety of images of retinal structures. Results are evaluated using metrics of accuracy, sensitivity, and specificity. It is expected that the proposed deep learning methods can significantly improve the automated analysis of retinal images, which is important for the diagnosis and monitoring of eye diseases. As a result, the article highlights the significance and promise of using deep learning methods in ophthalmology for automated analysis of retinal structures. These methods help improve the early diagnosis, treatment and monitoring of eye diseases, which can ultimately lead to improved healthcare quality and improved patient lives.

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1. INTRODUCTION

In modern ophthalmology, advanced deep learning technologies are being actively implemented [1], [2] for automated analysis of retinal structures. Some of the key methods that have attracted the attention of researchers and clinicians are EfficientNet [3], [4] and DenseNet [5], [6]. These methods provide powerful tools for image processing [7], [8] with a high degree of efficiency. The retina, as a key element of the visual system, is an object of attention in medical diagnostics. Assessing the condition of the retina and identifying pathologies requires accuracy and high sensitivity. In this context, deep learning methods [9], [10] provide a unique opportunity for automated analysis of retinal structures [11] with a high degree of accuracy. EfficientNet, originally designed to achieve an optimal balance between accuracy and computational efficiency, provides efficient neural network architectures [12]–[14]. On the other hand, DenseNet [15], based on dense connections, can efficiently extract features from images while preserving information at all levels. In this study, we focus on the application of EfficientNet and DenseNet for automated analysis of retinal structures [16]. These methods can significantly improve the processes of identifying and classifying pathologies [17], which in turn will facilitate the diagnosis and monitoring of eye diseases. Our work aims to investigate the effectiveness of these methods on a variety of data sets, as well as to evaluate their applicability in the clinical practice of ophthalmology The results of this study have the potential to significantly improve the accuracy and speed of diagnosis of ophthalmic conditions, opening new prospects for improving patient vision care. Viedma *et al.* [18] discusses methods for automatic analysis of retinal optical coherence tomography (OCT) images using deep learning (DL). The authors highlight the fundamental importance of such analysis in providing quantitative data on posterior ocular health and discuss the advantages of DL over traditional methods. The paper presents a detailed literature review, covering state-of-the-art DL-based methods for segmenting retinal layers in OCT images. The publication results highlight the success of DL in ocular image analysis, providing high performance and improved accuracy compared to previous machine learning methods and traditional image analysis. The authors also highlight promising directions for future research in this area.

Zekavat *et al.* [19] consider the importance of the microvascular network, especially in the fundus of the retina, as a key element in maintaining organ health and tumor development. They highlight that assessing this microcirculatory system using machine learning can provide new research opportunities for understanding human health and disease. The authors focus on the importance of whole-phenomenal and genome-wide analysis of the fundus vasculature and propose a large-scale assessment that can bring new insights into medical diagnosis and therapy. Jeong *et al.* [20] discuss the importance of automation in the field of ophthalmology, especially in the analysis of fundus images for the detection and diagnosis of various conditions such as diabetic retinopathy, age-related macular degeneration and glaucoma. They emphasize that the use of deep learning and machine learning techniques allows machines to efficiently interpret and analyze complex medical data, which can save doctors time and reduce the likelihood of diagnostic errors. The article provides an overview of recent research in this area, including screening and diagnostic methods, and retinal vasculature extraction from fundus images, with an emphasis on the challenges these systems face.

Kumar and Gupta [21] proposed an efficient hybrid deep learning method for segmentation and classification of retinal blood vessels. The images are pre-processed to improve quality, then a new enhanced fuzzy c-means (EFCM) clustering scheme is used to highlight important segments. Grouping images by vessel thickness helps reduce computational complexity. Experiments on digital retinal images for vessel extraction (DRIVE), structured analysis of the retina (STARE) and high-resolution fundus (HRF) databases show that the proposed model outperforms state-of-the-art methods, achieving high accuracy rates (99% for DRIVE, 98% for STARE and HRF). Abbood *et al.* [22] focus on the importance of early diagnosis of diabetic retinopathy (DR) to prevent vision loss in patients with diabetes. They present a fundus image enhancement algorithm used to improve the clarity and contrast of retinal photographs. The algorithm includes steps of cropping images and applying Gaussian blur to reduce noise. Experimental results conducted on EyePACS and MESSIDOR datasets show significant improvement in feature extraction and classification on enhanced images. The improved algorithm has also been successfully tested in smart hospitals as an internet of medical things (IoMT) application, demonstrating its potential for practical application in medical practice. Zhdanov *et al.* [23] present a method for diagnosing retinal dystrophy using electroretinography and develop an algorithm to support medical decision-making for an accurate diagnosis. Using machine learning methods, the algorithm is based on parameters extracted from wavelet scalograms of electroretinogram signals in patients of different ages. The study involves the use of a labeled database of electroretinogram signals from children and adults. The scientific novelty of the work lies in the development of special mathematical and algorithmic software for analyzing the parameters of the wavelet scalogram of the electroretinogram signal. The proposed algorithm also provides a more accurate classification of electroretinogram signals in adults and children compared to the classical analysis method.

2. METHOD

Research and analysis of the retina using deep learning methods, in this case, focuses on multi-class classification, also known as “muti label classification” [24]. This approach [25] assumes that each retinal image can be classified into several classes corresponding to different structures or states of the eye. In the context of ophthalmology, this may involve the classification of various diseases, changes or features of the retinal structures. Examples of classes include conditions such as macular degeneration, glaucoma, diabetic retinopathy, and normal retina. Multi-class classification using deep learning allows for more accurate and automated detection of a variety of retinal-based eye conditions. This is of great importance for early diagnosis and monitoring of eye diseases, which, in turn, helps to improve the quality of ophthalmic care.

The EfficientNetB0 architecture is part of an efficient family of models designed to optimize model accuracy and size. The strategy relies on complex scaling of three dimensions of the network, including width, depth and resolution, using a complex scaling factor. EfficientNetB0 is the base model in this family, serving as a starting point for the development of larger and more powerful variations. As shown in Figure 1, unlike traditional approaches that are limited to scaling only one dimension, EfficientNet simultaneously scales all three dimensions, which helps achieve higher accuracy with comparable or even smaller model size. DenseNet, in turn, stands out for its feature of "dense" connections between layers, where each layer receives input from all previous layers. Unlike DenseNet, EfficientNet does not use such a dense connection structure, which leads to differences in the number of parameters. DenseNet169 typically has more parameters due to its dense connectivity, which can increase model size and inference time. In terms of computational efficiency, EfficientNetB0 generally requires less computational resources to achieve comparable or even better performance compared to DenseNet169. On a number of tasks and datasets, EfficientNet can outperform DenseNet in accuracy with a lower number of parameters. The EfficientNetB0 model offers a modern approach to scaling neural networks, providing high performance in a comparatively smaller size compared to other architectures such as DenseNet169. The choice between these models should be based on the specific requirements of the task, available computing resources and data characteristics.

The application of deep learning methods such as EfficientNet and DenseNet in the field of ophthalmology is becoming a key step in automating the analysis of retinal structures. These innovative methods reduce the dependence on human error, providing faster and more accurate diagnosis of various eye conditions. Ultimately, such technologies offer promise for improving the quality of medical care and optimizing treatment strategies in ophthalmology.

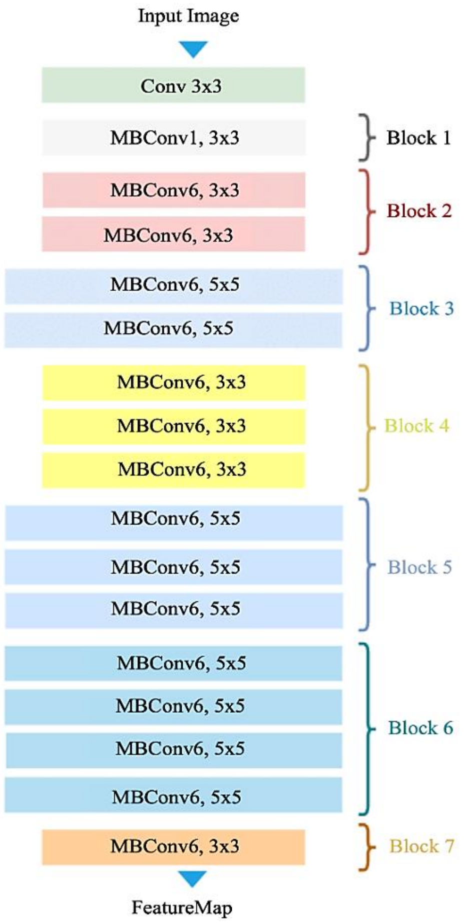


Figure 1. Architecture of deep learning models

3. RESULTS AND DISCUSSION

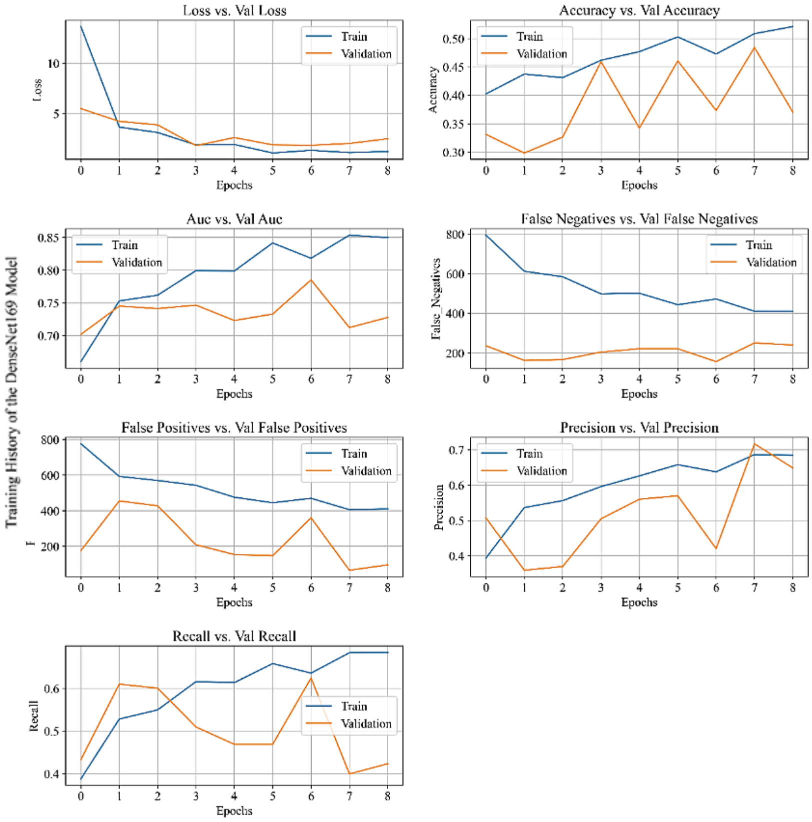
In our research, we successfully implemented deep learning methods for automated analysis of retinal structures in ophthalmology. Our results using the EfficientNet and DenseNet models confirmed significant advances in the field of automated analysis of ocular structures. In the context of our results, it is also important to discuss potential limitations and possible directions for future research. We see prospects for optimizing algorithms, expanding datasets to take into account the diversity of pathologies, and carefully adapting models to different patient groups. Thus, the use of deep learning, in particular EfficientNet and DenseNet, in the field of ophthalmology provides significant opportunities for automating and improving the processes of diagnosing eye diseases. As a result of the study, the performance of machine learning models, namely DenseNet169 and EfficientNetB0, was compared at the training and validation stages. The training and validation losses for DenseNet169 and EfficientNetB0 show high initial values, followed by a stable decrease and different final values. DenseNet169 shows a decreasing trend in loss over time, reaching a plateau, while EfficientNetB0 also shows a stable decrease in loss throughout training. Regarding accuracy, both training methods, DenseNet169 and EfficientNetB0, show increasing values over time as shown in Figure 2. However, EfficientNetB0 stands out for its higher accuracy value in the validation phase compared to DenseNet169. The final results indicate that EfficientNetB0 outperforms DenseNet169 in the considered metrics, exhibiting lower final loss and higher accuracy in the validation phase. Specifically, EfficientNetB0 exhibited a final training loss of 0.1152 and a validation loss of 0.2025, with a corresponding final training accuracy of 95.66% and validation of 92.77%. While DenseNet169 has final training and validation losses of 0.1811 and 0.2582, respectively, with a final training accuracy of 93.32% and validation accuracy of 91.12% as shown in Figure 2(a). Thus, based on the presented data, in Figure 2(b) the EfficientNetB0 model shows more effective results in comparison with DenseNet169, which confirms its advantages in the context of the considered performance metrics.

In this study, we conducted an in-depth analysis of retinal images to identify and classify various diseases. The retina is a unique structure of the eye that plays a key role in vision, and diseases of the retina can lead to decreased or loss of vision. Thus, rapid and accurate diagnosis of retinal diseases is a key aspect in ophthalmology. The total training sample consisted of 1920 images, which represented various retinal diseases. From the entire variety of possible classes of diseases, those that were represented in the largest number (more than 100 images for each class) were selected to provide a sufficient amount of data for training and validating the models. As a result, the following five classes were selected: i) diabetic retinopathy (DR) with 376 images, ii) macular hole (MH) with 317 images, iii) diabetic neuropathy (DN) with 138 images, iv) type-specific lymph node (TSLN) with 186 images, and v) optic disc cupping (ODC) with 282 images.

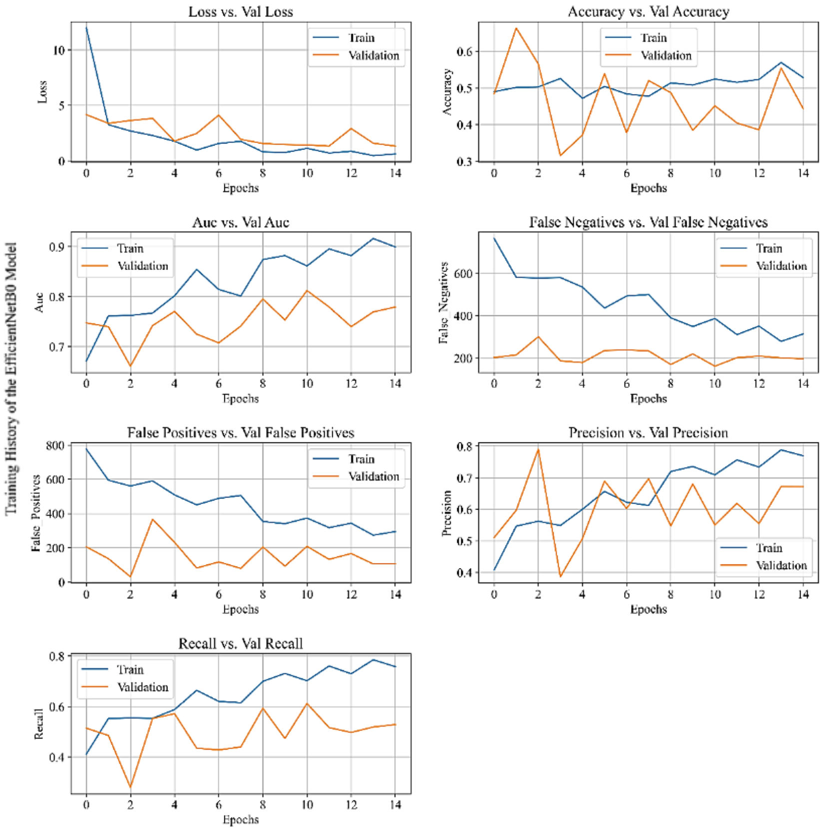
Two advanced deep learning architectures were used for image classification: DenseNet169 and EfficientNetB0. These architectures were selected based on their superior performance in a number of computer vision competitions and studies. After training and validation on retinal data, EfficientNetB0 performed better than DenseNet169 in terms of loss and accuracy during the validation phase as shown in Figure 3.

On the other hand, DenseNet, although it performed well, was slightly inferior to EfficientNet in some metrics. However, this method also provided high performance, making it a significant tool for automated analysis of retinal structures. It is important to note that the performance of each model may depend on the specific study conditions, characteristics of the data used, and diagnostic purposes. Thus, as shown in Figure 4, the choice between EfficientNet and DenseNet can be justified by the context of a particular task and the requirements of a particular clinical scenario.

By analyzing the loss and accuracy plots for both models, the loss plot for training and validation shows a steady decrease over time, indicating successful training. The initial loss is much higher, and although it also decreases over time, it remains higher compared to binary classification. The accuracy of training for binary classification and validation increases steadily, reaching high values. And the training accuracy of multi-class classification and validation also increases but remains lower compared to binary classification. Binary classification basically distinguishes between two classes or states, making the task relatively simple compared to multi-class classification, where the model must distinguish between many classes. In multi-class classification, the feature space becomes much more complex, and the model requires more training time and data to achieve similar performance to binary classifiers. In addition, with multiclass classification, the probability of random guessing is much lower than with binary classification, which can also affect the initial metrics of the model. In the case of retinal images, different diseases may have similar visual features, making the task of multi-class classification even more challenging. Effective learning in such environments requires more complex models, additional data, and possibly the use of data augmentation or transfer learning techniques. In conclusion, differences in performance between binary and multiclass classification can be explained by task complexity, data volume and quality, and model architecture features. This highlights the importance of choosing an appropriate model and learning strategy depending on the specific task and available data.



(a)



(b)

Figure 2. Accuracy metrics of deep learning models (a) according to the DenseNet169 model and (b) according to the EfficientNet model

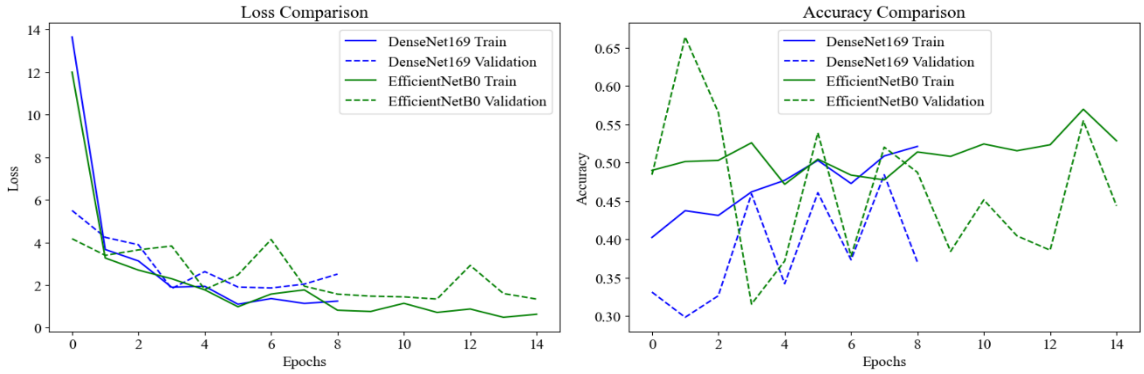


Figure 3. Comparative analysis of the performance of deep learning methods

Figure 4. Comparative analysis of binary and multiclass classification indicators

4. CONCLUSION

In conclusion, a study on the application of deep learning methods EfficientNet and DenseNet for automated analysis of retinal structures in ophthalmology revealed important conclusions. The EfficientNet method demonstrated impressive high accuracy in the task of analyzing retinal structures. The results obtained indicate its effectiveness and potential applicability in clinical practice. The effectiveness of EfficientNet, expressed in high classification accuracy values, highlights its ability to reliably and accurately recognize retinal pathologies. These findings may be important for improving diagnostic methods in ophthalmology, as well as for increasing the efficiency and efficiency of medical decisions. Our research demonstrates the potential of deep learning to improve diagnostic processes for ocular diseases, reducing reliance on human error and increasing the overall accuracy of retinal structure analysis. These methods not only speed up the diagnostic process, but also promise more accurate and reliable results. An important aspect of our work is the recognition of the need for further research in this area, including optimization of algorithms, expansion of datasets and adaptation of models to different patient groups. This opens up the prospect of creating more comprehensive decision support systems in ophthalmology, which could revolutionize the diagnosis and treatment of eye diseases.

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