https://doi.org/10.31891/csit-2024-1-3
UDC 004.391

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FEATURES OF THE MODIFICATION OF THE INCEPTIONRESNETV2 ARCHITECTURE AND THE CREATION OF A DIAGNOSTIC SYSTEM FOR DETERMINING THE DEGREE OF DAMAGE TO RETINAL VESSELS

Diabetic retinopathy is a retinal disease caused by diabetes. The progression of this disease can lead to blindness. Every year, the number of patients with this disease increases. Diabetic retinal damage can be slowed if it is diagnosed early. The article describes the features of the creation of a neural network model and the development of a system with high accuracy rates for the recognition of diabetic retinopathy.

The advantages of the InceptionResNetv2 convolutional neural network architecture are considered. This network uses residual connections that help facilitate the learning process. InceptionResNetv2 uses different methods to reduce the dimensionality of the feature map, making it more economical in terms of memory and computation.

This model has a number of advantages compared to other networks. InceptionResNetv2 can be applied to blood vessel segmentation in eye images with different resolutions.

In the study, modification of InceptionResNetv2 was carried out. The use of additional MaxPooling and Dense layers improved the speed and accuracy of the InceptionResNetv2 convolutional neural network. The Dropout layer is effectively used to prevent overtraining. The system for determining the degree of retinal damage of diabetic origin is implemented in the Python programming language. Model layers are built using the Keras library. Images from the set of EyePacs were processed by methods of cropping the black frames with a Gaussian blur filter and minimizing the effect of changing the position of the images.

During the research, it was found that 21 epochs are needed to achieve maximum accuracy. The program calculates the probability of an image belonging to a certain class with high accuracy. The recognition accuracy rate for class 1 was 98.6%, for class 2 - 98.5%, for class 3 - 98.3%, for class 4 - 98.15%, for class 5 - 98.1%.

Keywords: convolutional neural network, machine learning, diabetic retinopathy, retinal damage, InceptionResNetv2

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ОСОБЛИВОСТІ МОДИФІКАЦІЇ АРХІТЕКТУРИ INCEPTIONRESNETV2 ТА СТВОРЕННЯ ДІАГНОСТИЧНОЇ СИСТЕМИ ВИЗНАЧЕННЯ СТУПЕНЯ УРАЖЕННЯ СУДИН СІТКІВКИ ОКА

Діабетична ретинопатія - захворювання сітківки ока, спричинене діабетом. Прогресування вказаного захворювання може призвести до сліпоти Кожен рік кількість хворих з вказаним захворюванням зростає. Ураження сітківки ока діабетичного походження можна уповільнити, якщо його завчасно діагностувати. В статті наводяться особливості створення нейромережевої моделі та розробки системи з високими показниками точності розпізнавання діабетичної ретинопатії.

Розглянуто переваги архітектури згорткової нейронної мережі InceptionResNetv2. Вказана мережа використовує залишкові з'єднання, які допомагають полегшити процес навчання. InceptionResNetv2 використовує різні методи для зменшення розмірності карти ознак, що робить її більш економною з точки зору пам'яті та обчислень.

Ця модель має низку переваг у порівнянні з іншими мережами. InceptionResNetv2 може застосовуватися для сегментації кровоносних судин на зображеннях очей з різною роздільною здатністю.

В дослідженні проведено модифікацію InceptionResNetv2. Застосування додаткових шарів MaxPoooling та Dense покращило швидкодію та точність згорткової нейронної мережі InceptionResNetv2. Шар Dropout ефективно використано для запобігання перенавчанню. Систему визначення ступеня ураження сітківки ока діабетичного походження реалізовано на мові програмування Python. Шари моделі побудовано за допомогою бібліотеки Keras. Зображення з набору EyePacs були оброблені методами обрізання чорних рамок фільтром розмивання Гауса та мінімізацією впливу зміни положення зображень.

В процесі дослідження було виявлено, що для досягнення максимальної точності необхідна 21 епоха. Програма обчислює ймовірність належності зображення до певного класу з високою точністю. Було отримано показник точності розпізнавання для 1 класу 98,6%, для 2 класу - 98,5%, для 3 класу - 98,3%, для 4 класу - 98,15%, для 5 класу - 98,1% .

Ключові слова: згорткова нейронна мережа, машинне навчання, діабетична ретинопатія, ураження сітківки ока, InceptionResNetv2.

Introduction

The eye is an important human organ responsible for vision. Great attention should be paid to the health of the eyes. Eye diseases can lead to blindness and other complications. Symptoms of diseased eyes are blurring, worsening, and fluctuating vision. However, many eye diseases have no visual symptoms. Regular examination by a doctor is a guarantee of early diagnosis of certain diseases. One of the lesions of the retinal vessels is caused by diabetes. According to the World Health Organization, by the end of 2022, there were 422 million people with diabetes in the world. Diabetic retinopathy (DR) is a retinal disease caused by diabetes. Progression of this disease can lead to blindness. In 2021, 9.60 million people in the US (26.43% of people with diabetes) had diabetic retinopathy, and 1.84 million of them (5.06% of people with diabetes) had sight-threatening diabetic retinopathy [1]. There are also many people suffering from diabetic retinopathy in Ukraine. The number of patients with this disease is increasing every year. Diabetic retinal damage can be slowed if it is diagnosed early. If this is not done early, it may be too late. The disease initially manifests itself with minor symptoms, but its progression can lead to blindness. Diagnosing the degree of diabetic retinopathy is a difficult task. The doctor making the diagnosis must be highly qualified. An incorrect diagnosis can lead to incorrect treatment and further complications. Diabetic retinopathy is determined by doctors based on certain signs on images of the retina. In Ukraine, the infrastructure necessary for the determination of diabetic retinopathy is not sufficiently developed. Therefore, it is necessary to develop automatic methods of detecting this disease.

The success of research by scientists in determining the degree of retinal damage of diabetic origin is connected with the use of artificial intelligence. Diabetic retinopathy was determined using neural networks. The task of the research is to create a neural network model and develop a system with high accuracy rates for recognizing retinal damage of diabetic origin. The difference between the diseased and healthy eye is shown in Fig. 1.

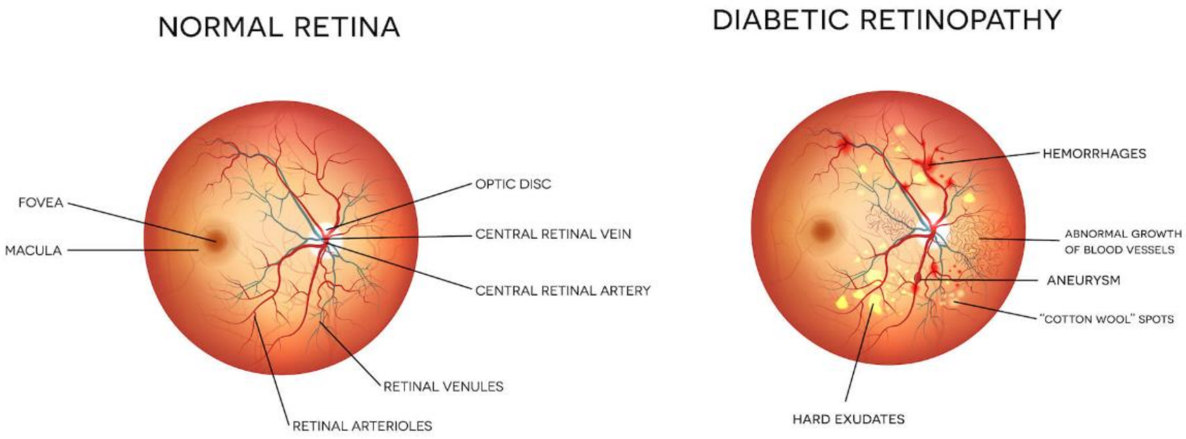


Fig. 1: Comparison between Normal and Diabetic Retinal Images [48]

Related works

Scientists successfully use artificial intelligence for medical diagnostic tasks [2, 3, 4] in studies on determining the degree of diabetic retinopathy. Works [5, 6, 7] show the advantages and disadvantages of using a large number of images to improve recognition accuracy. In work [8], scientists investigate such problems of deep learning as significant time for data processing. In the study [9], the authors examined datasets with diabetic retinopathy and found that the images were obtained from different cameras. Due to the obtained feature, researchers suggest always to do image processing. In [10], methods for solving such data set problems as noise, duplicates, and imbalance in the number of images of different classes are proposed. In [11], an algorithm was proposed that determines the quality of images. The study [12] established the feasibility of using artificial intelligence to assess image quality. It is appropriate to use convolutional neural networks to accurately determine the degree of diabetic retinopathy. In [13], a function was developed for setting the hyperparameters of the U-Net convolutional neural network. This mechanism can be used to solve the problem of determining the degree of damage to the retina. In [14], the MobileNet V3 architecture was optimized with the help of qualitative hyperparameter tuning. The authors of the study used the APTOS and EyePacs datasets. The model built in [14] can be implemented as a mobile application to support doctors in the treatment of patients with diabetic retinopathy. A complex model using several models of neural networks is proposed in [15]. In [16] and [17], the advantages of the DenseNet architecture in determining the degree of diabetic retinopathy are given. In the study [18], models based on VGG 16, InceptionV3, and MobileNetV2 architectures are used to determine the degree of retinal damage. Fine-tuning of certain layers of the InceptionResNetv2 and Inceptionv3 models is considered in [19]. The study [20] proposed a hybrid Inception-ResNet architecture. Effective mechanisms of transfer learning using DenseNet-169, VGG-19, ResNet101-V2, Mobilenet-V2, and Inception-V3 architectures are considered in [21]. The study [22] compares the effectiveness of the InceptionResnet-V2 and Densenet-121 models. In [23], a comparative analysis of DenseNet121 outperforms ResNet-101, InceptionResNetV2 and EfficientNetB0 models was carried out. In these studies, insufficient indicators of the accuracy of determining the degree of diabetic retinopathy were obtained. The built models did not have high enough speed. It is necessary to develop an architecture that provides improved accuracy and speed.

Modification of the InceptionResnetV2 architecture to determine the extent of damage to retinal vessels

We will present the features of the architecture of the InceptionResNetv2 convolutional neural network. The architecture of the network is presented in Figure 2. The network has 164 layers. InceptionResNetv2 is one of the most complex networks at the moment. This convolutional neural network uses residual connections that help facilitate the learning process. This feature allows information to flow freely through the network. The network uses Inception modules. This feature allows you to process information with different scales.

The InceptionResNetv2 network is robust to scaling. This convolutional neural network uses various methods to reduce the dimensionality of the feature map, which makes it more economical in terms of memory and computation. InceptionResNetv2 uses batch normalization to speed up the training process. The network has several exits. This feature makes it suitable for tasks in which certain characteristics need to be obtained. The InceptionResNetv2 network is open and available for use. The specified convolutional neural network can be downloaded from the TensorFlow repository. The InceptionResNetv2 network is actively supported by TensorFlow developers. InceptionResNetv2 works fast. This feature makes it suitable for image processing. InceptionResNetv2 is a convolutional neural network with high accuracy. This feature makes it suitable for image segmentation tasks.

The InceptionResNetV2 convolutional neural network can be used to segment blood vessels in eye images. This architecture has a number of advantages over other networks such as U-Net and FCRN. InceptionResNetV2 has better segmentation accuracy due to deeper architecture and more advanced Inception blocks. This network can be used for segmentation of blood vessels in eye images with different resolutions. InceptionResNetV2 has a useful feature for further extension and modification.

We will use this property to model a more efficient architecture. In the first step, we add the Max pooling layer. This layer reduces the size of images and compresses data. This results in improved network performance. The Max pooling layer makes the network more resistant to noise and interference. This layer helps the network to extract the most important features from the image. In the next step, we add a Flatten layer. Its use reduces the dimensionality of the data. This feature improves network performance. In the next step, we add a Dense layer with 64 neurons. With the specified layer, we use the Relu function for the nonlinearity of the model. In the next step, we add a Dropout layer of 20% to avoid overtraining. The Dense layer with the softmax function will allow you to determine the probability of the image belonging to one of 5 classes. The constructed neural network model is presented in Fig. 2.

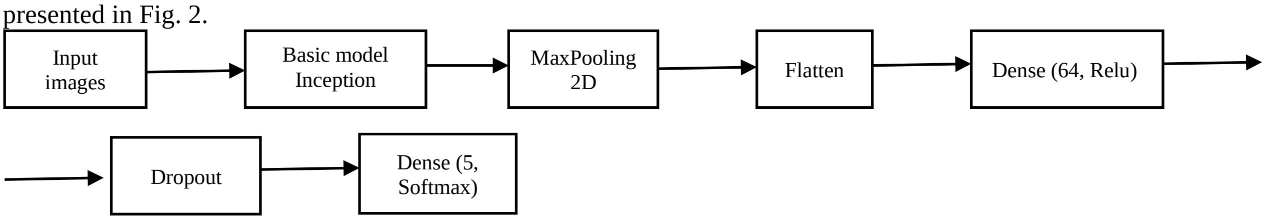


Fig. 2 Modified InceptionResNetv2 model

SGD, Momentum, RMSProp, Adam optimization algorithms were analyzed. This analysis showed that it is advisable to use the Adam method. The use of this method made it possible to obtain high performance indicators of the network.

The EyePacs dataset containing 35126 images of 5 classes was selected for further development. Class 1 – images without diabetic retinopathy. Class 2 is the initial stage of diabetic retinopathy. Class 3 – moderate stage of diabetic retinopathy. Class 4 – severe non-proliferative retinopathy. Grade 5 – proliferative retinopathy. Each stage of the disease is more difficult than the previous one.

The specified set contains 25810 images of class 1, 2443 images of class 2, 5292 images of class 3, 873 images of class 4, 708 images of class 5. All images were divided into training and testing datasets. 80% of the images were selected for the training sample. 20% of the images were selected for the test sample. The training dataset contained 28,100 images. The test dataset consisted of 7026 images. An example of images from the EyePacs dataset is shown in Fig. 3.

(a) (b) (c) (d)

Fig.3 Non-proliferative DR mild; (b) non-proliferative DR moderate; (c) non-proliferative DR severe; (d) proliferative DR

The system for determining the degree of retinal damage of diabetic origin is implemented in the Python programming language. Model layers are built using the Keras library. Images from a set of EyePacs were processed. The method of cropping black frames is used to obtain a clear image. The filter removes unnecessary black frames. This extraction is not done if the image is dominated by black. The color image is converted to black and white. In the next step, the method of cropping black frames is applied to a black and white image.

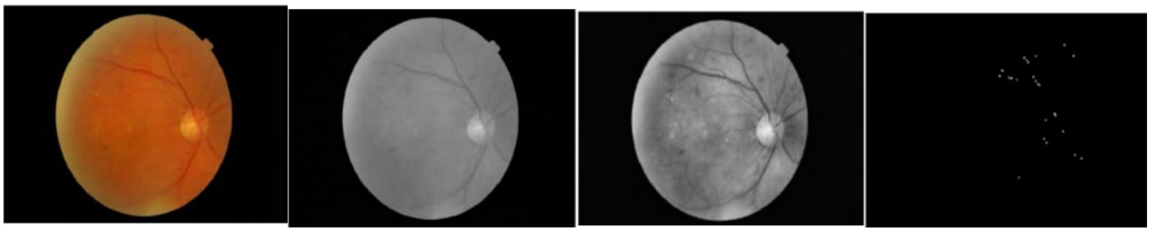
The image has been processed with a Gaussian blur filter to improve clarity. The sharpness of the necessary elements of the image was achieved by reducing the blur radius.

A modified convolutional neural network in the learning process creates filters that help classify images in different positions. The accuracy metric was used during compilation.

The lr parameter of the Adam optimizer was set to 0.000001. The fit_generator method was used to train a convolutional neural network.

Experiments

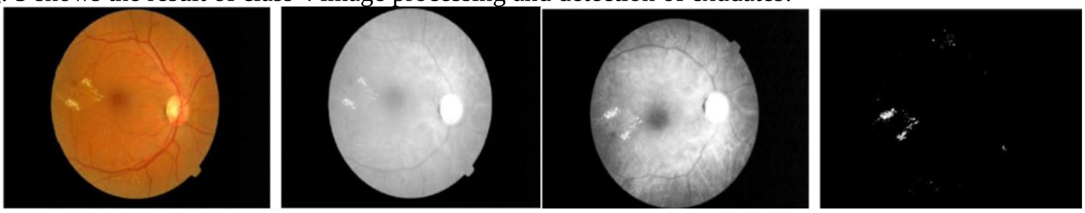
Image processing was performed. Figure 4 shows the result of class 2 image processing and microaneurysm detection.



a) b) c) d)

Fig.4. the result of image processing in class 2: *a* – RGB image; *b* – halfton image; *c)* – image after improving the contrast; *d)* microaneurysm image

Fig. 5 shows the result of class 4 image processing and detection of exudates.



a) b) c) d)

Fig.5. the result of image processing in class 4: *a)* RGB image; *b)* red channel; *c)* – image after improving the contrast; *d)* exudate image

The study initially used an unbalanced data set. Insufficiently high accuracy rates were obtained. To balance the data, the weight was calculated for each class and the parameter was integrated into the built model. This mechanism balances the distribution of data. The values of the weights are given in Table 1.

Table 1

Weight values

Degree of diabetic retinopathy	Number of images	Weight values
1	25810	1.00000000
2	2443	10.56487925
3	5292	4.87717309
4	873	29.5647193585
5	708	36.4548022599

The study analyzed the accuracy indicators of the basic and modified InceptionResNetV2 models. The modified InceptionResNetV2 architecture showed better results. During the research, it was found that 21 epochs are needed to achieve maximum accuracy. The program calculates the probability of an image belonging to a certain class with high accuracy. The following indicators of recognition accuracy on the training set were obtained: for 1st grade – 98.6%, for 2nd grade – 98.5%, for 3rd grade – 98.3%, for 4th grade – 98.15%, for 5th grade – 98.1%. The following recognition accuracy values were obtained on the test set: for class 1 – 98.2%, for class 2 – 98.1%, for class 3 – 98.05%, for class 4 – 98.05%, for class 5 – 98.0%.

Table 2 shows the recognition accuracy values for class 2 during training for 21 epochs.

Table 2

Accuracy values for class 2

Epoch number	Accuracy on the training set	Accuracy on the control set
1	0.861	0.854
2	0.872	0.867
3	0.885	0.872
4	0.901	0.884
5	0.909	0.897
6	0.917	0.911
7	0.923	0.914
8	0.927	0.919
9	0.933	0.924
10	0.937	0.931
11	0.941	0.935
12	0.946	0.940
13	0.949	0.942
14	0.952	0.947
15	0.958	0.951
16	0.964	0.958
17	0.967	0.962
18	0.972	0.968
19	0.979	0.971
20	0.983	0.975
21	0.985	0.981

An analysis of the indicators of the cost function of the basic model and the modified InceptionResNetV2 model was carried out. The following values of the recognition cost function on the training set were obtained: for class 1 – 0.16, for class 2 – 0.22, for class 3 – 0.29, for class 4 – 0.34, for class 5 – 0.38. The following indicators of the cost function on the test set were obtained: for the 1st class – 0.21, for the 2nd class – 0.25, for the 3rd class – 0.35, for the 4th class – 0.39, for the 5th class – 0.43. The obtained indicators are shown in Table 3

Table 3

Values of loss function

Degree of diabetic retinopathy	Values of loss function on the training set	Values of loss function the control set
1	0.16	0.21
2	0.22	0.25
3	0.29	0.35
4	0.34	0.39
5	0.38	0.43

The use of additional MaxPooling and Dense layers improved the speed and accuracy of the neural network. The Dropout layer is effectively used to prevent overtraining. The Adam optimization method improved network performance

Conclusions

The use of the InceptionResNetv2 convolutional neural network to determine the degree of diabetic retinopathy is substantiated. Gaussian blurring, removal of black frames and minimization of the effect of changing the position of images improved the quality of post-processing. The modified InceptionResNetv2 network has higher accuracy and speed than the base model. High recognition rates were obtained for each of the five image classes of the data set.

Successful performance testing of the application under various hardware and software configurations was carried out. The trained model and software can be used under different operating systems. Compared with the models proposed in previous studies, the developed system has better recognition accuracy and speed.

The developed application can be used in hospitals, polyclinics and other medical institutions. The prospect of further research is the use of the modified convolutional neural network InceptionResNetv2 in other tasks of medical diagnostics.

Use of the InceptionResNetv2 convolutional neural network to determine the degree of diabetic retinopathy is substantiated. Gaussian blurring, removal of black frames and minimization of the effect of changing the position of images improved the quality of post-processing. The modified InceptionResNetv2 network has higher accuracy and speed than the base model. High recognition rates were obtained for each of the five image classes of the data set.

The perspective of further research is to modify the structure of the convolutional neural network InceptionResNetv2 in order to improve the recognition accuracy. Compared with the models proposed in previous studies, the developed system has better recognition accuracy. Successful performance testing of the application under various hardware and software configurations was carried out. The trained model and software can be used under different operating systems. The developed application can be used in hospitals, polyclinics and other medical facilities.

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