SINERGI Vol. 28, No. 1, February 2024: 55-62
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2024.1.006

Early detection of diabetes potential using cataract image processing approach

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Abstract
Diabetes is a disease characterized by a high level of sugar in the blood. The disease occurs because of a disruption in the metabolic system when insulin is not produced effectively and functions properly. High blood sugar levels, for an extended period of time, can harm a few organ systems, including the heart and kidneys. Moreover, it may cause blindness or death if it is not carefully monitored. Because diabetes symptoms are rarely seen, one of the factors that may cause diabetes is self-awareness. Thus, with Artificial Intelligence, this problem can be solved. Artificial intelligence studies how machines can function like humans. This study implemented a Convolutional Neural Network algorithm with (1) input layer, (2) feature learning layer, (3) classification layer, and (4) output layer as the architecture for AI. The accuracy of the developed AI model was measured from its precision, recall, and f1-score. The results show that the model obtained 90% precision, recall, and f1-score for real-world cases found in two hospitals located in Solo and Yogyakarta, Indonesia. According to the results of the tests, 9 out of 10 patients were correctly predicted as having a high risk of diabetes based on their eye images.

Keywords:
Artificial intelligence;
Cataracts;
Diabetes;
Early detection;

Article History:
Received: June 2, 2023
Revised: July 2, 2023
Accepted: August 20, 2023
Published: February 2, 2024

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INTRODUCTION

The number of diabetes sufferers increased by 167% from 2011 to 2021. It makes diabetes the third most deadly disease in Indonesia. Diabetes may lead to heart disease, kidney disease, blindness, and death. Despite the development of existing diabetes treatment methods, 73.7% of diabetics in Indonesia are estimated to have been undiagnosed. This highlights the need to rapidly detect the symptoms of diabetes and take the necessary preventive measures [1, 2, 3]. According to a study conducted on type two diabetes patients in Indonesia, the natural cause of the increase in diabetes death rates is a lack of awareness of the disease's early symptoms. This factor is believed to be triggered by the difficulty of early detection of diabetes symptoms, such as frequent hunger, frequent urination, tingling feet, etc. People in the early stages of diabetes often ignore these symptoms, which causes the disease to progress to its lethal stage [4][5].

In the context of cataracts, the characteristics of cataracts in diabetics are different from those of non-diabetic cataracts. Diabetes can accelerate the development of cataracts. In fact, 50% of cataract cases are in the 65-74 age group, and 70% of cases are in the 70+ age group. According to experts, hyperglycemic conditions can alter eye shape and function. These conditions can lead later to faster cataract formation.

Diabetes is not necessarily associated with cataract development. However, hyperglycemia accelerates cataract development. Age also raises the risk of having diabetes and cataracts.

Around 10 million people in Indonesia were anticipated to have diabetes in 2018, and in the following ten years, that number is predicted to increase threefold. The risk of getting diabetes in the younger age group is increasing due to the 2:1 population ratio between the young and the elderly. Due to a bad lifestyle, it is estimated that only 22.8% of Indonesia's population engages in regular physical activity. The lack of physical exercise in this age group is caused by a number of variables, but modernity and urbanization are thought to be the main ones [6, 7, 8, 9]. Diabetes issues may be solved by Artificial Intelligence (AI). Using AI, users may quickly identify anomalies and come up with solutions to the issues. According to a study by ophthalmologists in the US, 22 out of 37 respondents had their retinas accurately identified for diabetes identification. Then, of the same 37 respondents, AI could accurately identify 36 of them. This demonstrates how AI can aid professionals in reducing human error [10, 11, 12].

Several AI researchers investigated how machines could work like humans [13][14]. AI technology could overcome this problem. Babylon app is one of the AI applications in the health field. Babylon is originally a health consultation company from the United Kingdom. It helps people detect early symptoms of diseases. With AI, it provides a data-driven approach to support clinical decision-making and health policymaking [7, 9, 10].

Similar technology was also developed in a study conducted by the American Academy of Ophthalmology. The results showed that the artificial intelligence (AI) system had a higher sensitivity for detecting diabetic retinopathy than eye specialists in general with clinical reference standards. Artificial intelligence has the potential to serve as a low-cost diabetes detection tool and help address diabetic eye screening [16, 17, 18, 19]. Moreover, using AI to detect glaucoma will avoid the diagnosis solely by doctors.

Previous studies developed machine learning models to achieve an autonomous detection strategy [20, 21, 22]. Currently, machine learning has achieved the leading features for forecasting and handling a severe disease. Other previous studies presented prediction models through machine learning procedures and using image processing to predict glaucoma [19][23].

Then, comprehensive reviews were done on those previous studies to focus on glaucoma and its cause, effects, types, and possible treatments. Clinical learning, deep learning, machine learning, and image data were used to predict this disease effectively [24, 25, 26].

Currently, glaucoma is the second most common disease of blindness. However, a single test cannot detect blindness. Figure 1 shows the details anatomy of the eyes. People with diabetes have higher risks of glaucoma than those non-diabetics. Diabetic patients are mostly affected by open-angle glaucoma because high blood sugar damages the small blood vessels in the eyes. This damage can cause a severe eye disease known as diabetic retinopathy. This disease hinders the drainage of fluid from the eye and causes glaucoma [19].

With the support of the results of previous studies, the early symptoms of diabetes can be detected more easily from the eyes. This study aimed to classify cataract images by camera cellphone to accelerate the detection of early symptoms of diabetes. The quality measurement analysis was conducted using f1-score, precision, and recall. Thus, Artificial Intelligence (AI) technology is expected to help people get better medical care for their health problems.

Previous studies on cataract detection commonly used special medical equipment and facilities. This study developed a smartphone application that used AI to distinguish between eyes with high-risk and non-high-risk of diabetes. Analysis of the images showed that 9 out of 10 images were correctly predicted. This study proposed a concept based on the prevailing notion to make diabetes detection simpler by utilizing AI in order to identify eye scans. Therefore, users will be able to assess the potential for having diabetes before visiting an established medical facility.

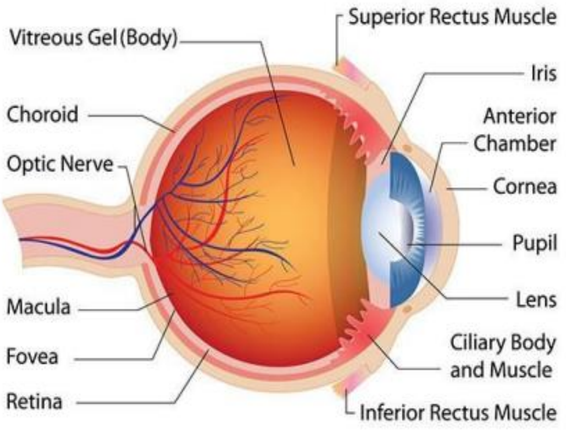


Figure 1. The details of eye anatomy [27]

METHOD

This multicenter study was conducted with Slamet Riyadhi and Yogyakarta City Hospitals. There were 10 respondents that took part in the survey. They were then divided into two groups: (a) the non-diabetic group and (b) the diabetic group with cataracts. In this study, information was gathered through interviews and photographs of the participants' eyes. In July 2022, this study was started by submitting the necessary paperwork (permits and administrative procedures) at the research site. The number of cases of diabetes and cataracts was taken into consideration when choosing the research site. Prior to beginning the trial, the researchers worked with medical professionals to choose participants in accordance with the inclusion criteria. The researcher then went over the steps involved in conducting the study with the respondents. The ethics committee at each research site must first approve the techniques for recruiting respondents, the research procedures, and the research protocols before the study started [16, 17, 18, 19]. Artificial intelligence is closely related to neural networks, and one of the best-known neural network algorithms is convolutional neural networks (CNN). Figure 2 shows the flowchart of the convolutional neural network performed in this study.

Prior to data collection, the patient's medical record had been examined and seen, and information on the patient's age, medical history, and health problems had also been directly collected during the interview process. Some criteria were determined in selecting the research participants.

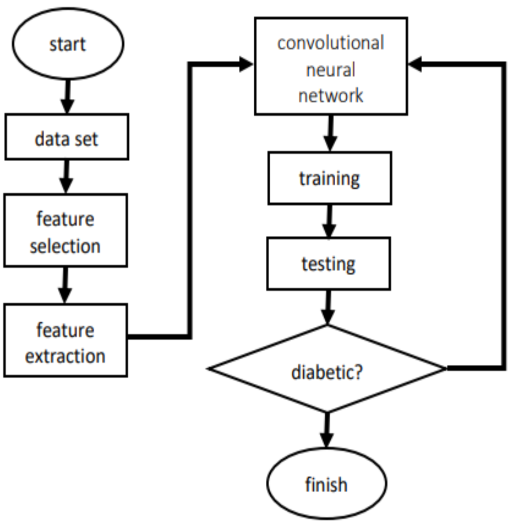


Figure 2. Flowchart of CNN

Having diabetes for at least a year, being between the ages of 25 and 50, and not pregnant are all requirements, as listed in Table 1. By dividing the body weight by the square of the person's height, the body mass index was calculated. During the interviews, information about the participants' ages as well as symptoms of cataracts and diabetes was gathered [23, 24, 25].

A Canon Mark II DSLR camera with a magnifying lens was used to capture images of the eyes. The generated photos were then saved and put through machine learning to create an AI model. The noise in the image would first be decreased, and then its quality and sharpness were enhanced before it was used as processed data. Next, the AI model was used in the processed data as a data source. The Convolutional Neural Network (CNN) algorithm was used to construct the machine learning model, and the desired final label output was two multi-classes [26, 27, 28, 29, 30, 31]. Figure 3 shows the CNN algorithm.

Data used in this study were collected from diabetes patients and healthy individuals observed at Slamet Riyadhi Hospital and Yogyakarta City Hospital. They were collected from people between the ages of 55 and 70, with high blood sugar levels over 200 mg/dl and under 200 mg/dl.

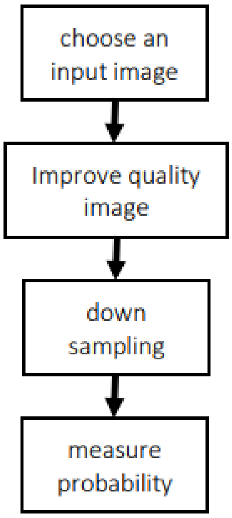


Figure 3. CNN Algorithm

Table 1. Respondent Criteria

Inclusion	Exclusion
Age between 25 to 60 years old	Not pregnant
Having diabetes for at least a year	Over 60 years old and under 25 years old

This study employed a conventional F1-metric score measurement that includes (a) precision and (b) recall to assess the efficacy of the artificial intelligence model for a specific object [30, 32, 33, 34, 35].

The convolutional neural network (CNN) has a few layers. CNN is built up of basically three types of main layers, consisting of convolutional layer, pooling layer and a fully connected layer with a rectified linear activation function (ReLU). This application is for analyzing signals which are one-dimensional, so it uses Convolution 1D layers, pooling 1D layers, and fully connected layers. CNN takes the form of time series data in one dimensional wherein the data are arranged in the order of sequential time instants. The last layer is called the output layer [11][12]. The first phase in CNN was to choose the 2D image that would be used as input. The next step was to improve 2D image quality with ReLU activation. ReLU is a type of activation that creates a zero barrier. ReLU is somehow like the quote "while x is a real number and x is zero, x equals 0. While x is zero, x remains x".

The function ReLU: $\mathrm{R} \rightarrow \mathrm{R}$ (1)

defined by ReLU$(\mathrm{x}) = \max\{x, 0\}$. (2)

It is differentiable save at the origin and meets

ReLU$'(\mathrm{x}) = 0 \; for \; x < 0$, and (3)

ReLU$'(\mathrm{x}) = 1 \; for \; x >$ 0. (4)

The next phase was the acceleration of the computation process with down-sampling. This phase was designed to keep more resources available for single-process computation. In the following phase, the extracted features from previous layers were rebuilt into a vector in the output layer. In the last phase, the probability was measured in every class with softmax activation [16][17]

This study was conducted according to related journal articles and expert suggestions. A neural network's quality measurement was carried out using the F1 metric score, including precision and recall. A confusion matrix was used in this study to ensure that the neural network's quality was maintained [16, 17, 18, 19].

Moreover, through a confusion matrix, developers could look for errors in the AI model. It improved their perception of the false positive and false negative. Precision is an analytical method to evaluate a neural network model mathematically. This method measures the number of correctly positive cases compared to the total number of positive cases predicted by the AI model. A higher precision value indicates that the AI model can correctly predict more positive cases [20, 21, 22].

The difference between precision and recall is the comparison. The total number of correctly predicted positive cases compared to positive in real cases is referred to as recall. Moreover, the formulas for calculating precision, recall, and F1-score are presented below [26][27].

$$Precision = \frac{TP}{TP+FP} \quad (5)$$

$$Recall = \frac{TP}{TP+FN} \quad (6)$$

$$F1\text{-}score = 2 \times \frac{precision \times recall}{precission + recall} \quad (7)$$

TP = The number of correct predicted positive cases
TN = The number of correct predicted negative cases
FP = The number of incorrect predicted positive cases
FN = The number of incorrect predicted negative cases

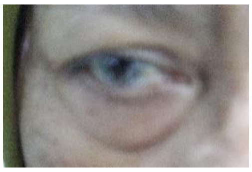
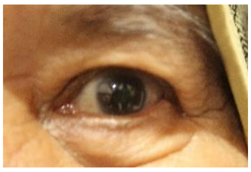
RESULTS AND DISCUSSION

The objective of this study is to create a neural network for the early detection of potential diabetes using eye images captured by a cellphone camera. Machine learning was used to distinguish between the eyes of diabetic and non-diabetic patients. There are 48 images used in this study, including those taken from cataract and non-cataract patients. There are a few parameters used in this study, including the validation of graph accuracy, the graph accuracy loss vs. validation of graph accuracy loss, and the confusion matrix.

In order to classify the images obtained, an algorithm was used. Then, to achieve the best results for detecting cataracts, it is necessary to fine-tune the required pre-trained models and adjust the epochs. The proposed algorithm has several steps, namely (1) Starting with the input of RGB images, (2) Converting RGB to Gray Scale, (3) Removing the noise of the image through discrete wavelet transformation techniques, (4) Converting the noise-free gray-scale images into RGB images, (5) Resizing the images refer to the required model, (6) Applying the pre-trained models to train the updated data, and (7) Classifying the test data and predict the actual output.

Table 2 shows the comparison between the outcomes of calculating the likelihood of acquiring diabetes symptoms using artificial intelligence to the results obtained from actual medical conditions. The respondents were at the age between 52 and 60 years. The respondents had diabetes with the shortest period of 6 years, and the longest period of 14 years. The most recent level of fasting blood sugar average is 200 mg/dl.

Table 2. Comparison between Prediction with AI and the Real Condition

Images	Prediction	Real condition	Age (years old-y.o)	Diabetes Duration (years)
	86% Cataract indicated	Unoperated cataract patient	59	12
	1% Cataract indicated	Non-cataract patient	53	8
	55% Cataract indicated	Unoperated cataract patient	50	10
	72% Cataract indicated	Unoperated cataract patient	60	13
	57% Cataract indicated	Unoperated cataract patient	58	12
	1% Cataract indicated	Non-cataract patient	55	9
	38% Cataract indicated	Unoperated cataract patient	56	12
	71% Cataract indicated	Unoperated cataract patient	59	14
	95% Cataract indicated	Unoperated cataract patient	57	10
	84% Cataract indicated	Unoperated cataract patient	52	6

Based on Table 2, it can be concluded that the average age of respondents is 55.9 years old. Then, the average duration of having diabetes is 10.6 years. Data prediction using AI shows that cataracts are detected when it reaches 1%, 38%, 57%, 72%, and 95%. This can be validated through real condition data from doctor's examination results which show non-cataract, unoperated cataract, unoperated cataract, unoperated cataract, and unoperated cataract patients respectively.

The data were obtained after measurements using the F1 metric score for (a) precision and (b) recall. The fit model graph presenting data from training and validation is shown in Figure 4.

The error in training and validation data was found using the mean square error (MSE) technique. Based on the data in Figure 4, the error found is 0.012. The very small value of MSE shows that the predicted results are mostly like the actual condition. The best-predicting results refer to the chosen method with the least error rate. Besides having the minimum error, it is also supported by the greatest predicting value.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}\left(a_i - \hat{a_i}\right)^2 \quad (8)$$

where a_i, $\hat{a_i}$, and n are the training, validation, and data number respectively.

This study achieved over 90% accuracy and validation accuracy. It was found that participants without cataracts had longer histories of diabetes and higher fasting blood sugar levels than diabetics with cataracts. In addition, they also had a history of visual impairment, which is diagnosed as cataracts. Figure 4 shows that there is an enhancement in model machine learning up to 20 epochs. Meanwhile, Figure 5 shows the confusion matrix.

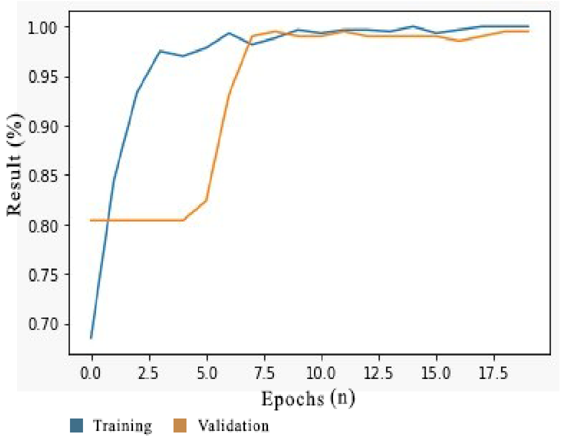


Figure 4. Comparison between Training and Validation

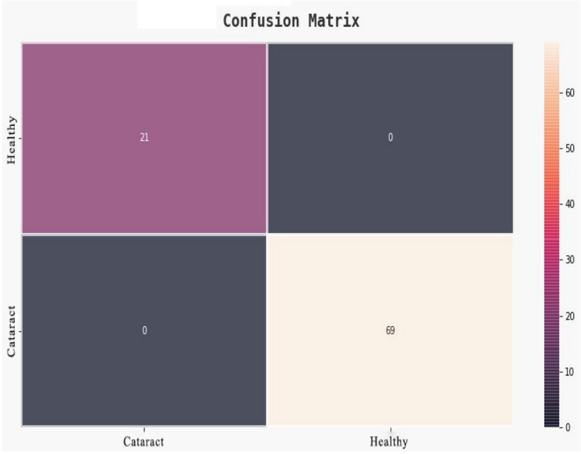


Figure 5. Confusion Matrix

It is shown in Figure 5 that there are 21 correct predicted cataract eye images and 69 healthy eye images. Moreover, model machine learning has been tested in two hospitals in Solo and Yogyakarta. If only seen directly (no AI is used to examine the eyes), diabetics with cataracts and diabetics without cataracts share the same physical characteristics. Thus, assessing the likelihood of diabetes purely on the basis of eye images is not viable. Then, it was found that the variable of age and high blood sugar hasten cataracts to develop.

CONCLUSION

Artificial intelligence is a form of technology that helps humans in every aspect, including health. In this study, Convolution Neural Networks were implemented as a neural network algorithm. The AI model's quality was assessed using the f1-score, precision, and recall. The results showed that the percentage of each metric is over 90%. The AI model was able to correctly predict 9 out of 10 cases in the examples shown. The prediction results have been compared to the respondent's blood sugar levels taken from two hospitals in Yogyakarta and Solo. The prediction results are similar to the real condition of respondents with blood sugar levels reaching more than 200 mg/dl.

ACKNOWLEDGMENT

The researchers would like to express their gratitude to Google Indonesia and the Indonesian Ministry of Research and Higher Education for being ready to support this study. We would not have been able to finish it without the support and assistance. We also want to collaborate more with both institutions in the next projects. After all, the results of this study are expected to benefit society.

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