Fuzzy modeling network type 2 and principal component analysis for the diagnosis of diabetic retinopathy

A Damayanti¹, S Maimunah², and A B Pratiwi³
¹,²,³ Department of Mathematics, Faculty of Science and Technology, Universitas Airlangga, Surabaya, Indonesia

E-mail: ¹aulid@fst.unair.ac.id

Abstract. Diabetic retinopathy is a disease caused by vascular complications of diabetes mellitus. The more increasing number of people with diabetes mellitus every year, then indirectly the chances of someone's eye experiencing diabetic retinopathy disorders are also increasing. Fundus photos are one way to detect diabetes mellitus in the retina of the eye. The stages used in the detection process of diabetic retinopathy include the stage of pre-processing fundus images namely grayscale and histogram equalization processes, the stage of reducing image size using Principal Components Analysis (PCA) and the stage of diabetic retinopathy detection on fundus images using fuzzy modeling network type 2. Fuzzy modeling network type 2 is a method using multilayer neural network architecture with backpropagation learning and fuzzy systems for its rules. The results of the validation system test show that the process of detecting diabetic retinopathy using the type 2 fuzzy modeling network algorithm is obtained the accuracy of 80%.

1. Introduction
Diabetes mellitus is a metabolic disease caused by high blood sugar levels over a long period of time. The number of people with diabetes mellitus is expected to increase in the next few years, as in 2013 the number of people with diabetes mellitus was in the range of 382 million and estimated to increase to 592 million people with diabetes mellitus by 2035 [1]. Diabetic retinopathy is a vascular complication caused by diabetes mellitus which can cause blindness. Diabetic retinopathy occurs because too much sugar in the blood clogs the small blood vessels in the retina [2]. The retinal fundus image of the eye is now widely used to determine eye blindness or other diseases, as in the research conducted by Tomas Walter, et al in the title "A Contribution of Image Processing to the Diagnosis of Diabetic Retinopathy - Detection of Extinct in Color Fundus Images of the Human Retina".

The artificial neural network is a learning method that is used to recognize the characteristics of data. Artificial neural networks are widely applied in various studies because they can model non-linear systems [3]. Fuzzy modeling network type 2 (FMN Type 2) is one of the back-propagation methods for identifying fuzzy rules and membership functions automatically by modifying the weights of artificial neural networks using the back-propagation algorithm. FMN Type 2 is a development of FMN Type 1 which has a more complex formation so that it is able to determine the right membership function both in modeling a variety of opinions from different individuals, while in FMN Type 1 is only able to handle a limited or no level of uncertainty or can’t fully handle linguistic and numerical uncertainties related to the environment and unstructured changes [4].
Principal Component Analysis (PCA) is a process used to reduce the size of the image used, the Principal Component Analysis is considered to be able to solve this problem because the Principal Component Analysis has a simpler computational complexity and is able to provide good results even with limited data [5].

In this study, FMN Type 2 was used to diagnose diabetic retinopathy by reducing the size of the eye retinal fundus image using PCA to simplify the diagnosis process and it was hoped that the built system could recognize the pattern of fundal images well so that the diagnosis was more accurate.

2. Methodology
The steps taken in this study include pre-processing, image size reduction, and detection process using fuzzy modeling network type 2 of backpropagation.

2.1. Preprocessing
Preprocessing is the initial stage of the process before carrying out the main stage, one of which is the image processing process. Image processing is one of the ways to get certain information by inserting an image which will then produce output in the form of images or can also be part of the image. The purpose of image processing is to improve image quality in order to facilitate the implementation of computer programs. In this study, the image processing process is grayscale, and histogram equalization.

2.1.1. Grayscale
Grayscale is the stage of taking all pixel data in the image in the form of three-color information (red, green, blue) into three different matrices with values represented between 0 and 255. To change the image to be grayscale it will be done by looking for the average value of the three colors that have been taken. The grayscale calculation formula is shown in equation 1 [6].

\[ S = \frac{r + g + b}{3} \]  

where:
- \( r \) = value on red layer
- \( g \) = value on green layer
- \( b \) = value on blue layer

2.1.2. Histogram Equalization
Histogram equalization is a histogram smoothing process, by reading each pixel of RGB and making it an input on the histogram, then the results are levelled with reference values around it. The formula for calculating histogram equalization is shown in equation 2 [7].

\[ w = \frac{c_w th}{n_x n_y} \]  

where:
- \( w \) = gray value results from histogram equalization
- \( c_w \) = cumulative histogram of \( w \)
- \( th \) = image size

2.2. Principal Component Analysis (PCA)
PCA is a process to reduce the size of the image by means of a linear transformation to produce a new coordinate system with maximum variance [8]. The steps of the principal component analysis include the following:

a. Change the sized image matrix \( \eta \times \eta \) become a vector matrix \( A \) with the size \( \eta^2 \times 1 \).

b. Arrange a matrix A. Matrix A is a collection of several vectors \( A_i \).
\[ A = \begin{bmatrix} A_1 & A_2 & A_3 & \ldots & A_m \end{bmatrix}, \text{with } m \text{ is the number of images processed.} \]

c. Calculates the average for each column in the matrix \( A \).

d. Calculate the mean adjusted data or matrix \( B \).

\[
B = A - \overline{A}, \text{ where } \overline{A}_{ij} = \frac{\sum_{j=1}^{m} x_j}{m}
\]  

(3)

e. Calculate covariance matrix \( (C) \).

\[
C = \frac{1}{n^2 - 1} B x B'
\]  

(4)

f. Calculate eigen values and eigen vectors from the covariance matrix

\[
C - \lambda I = 0 \text{ and } (C - \lambda I)\chi = 0
\]  

(5)

where:

- \( I \) = Identity matrix
- \( \lambda \) = eigenvalues
- \( x \) = eigenvectors

g. Sort eigenvectors with eigenvalues descending. The eigenvalue of the vector corresponding to the largest value of the eigenvalue has the most dominant characteristic, while the value of the eigenvector corresponding to the smallest eigenvalue has the least dominant characteristic.

h. Calculates the principal component value or the \( P \) matrix.

\[
P = F \times A
\]  

(6)

i. Calculates matrix of \( Y \)

\[
Y = A \times P'
\]

j. Look for the normalization matrix from the \( Y \) matrix with the formula:

\[
\text{normalization}_{n_{ij}} = -1 + \frac{2}{\text{max value} - \text{min value}} \left( Y_{ij} - \text{min value}_j \right)
\]  

(7)

where:

- \( \text{max value} \) = the highest element of the matrix of \( Y \)
- \( \text{min value} \) = the lowest element of column \( j \) of matrix \( Y \)
- \( Y_{ij} \) = an element of the matrix \( Y \) to \( i \) and to \( j \)

2.3. **Fuzzy Modeling Network Type 2 (FMN Type 2)**

FMN type 2 is a fuzzy modelling method through back-propagation learning introduced by Horikawa in 1997. FMN type 2 is a hybrid of artificial neural networks with fuzzy systems. The artificial neural network architecture as shown in Figure 1 and the calculation uses fuzzy. The rules for FMN type 2 are given in Equation 8 [4].

\[
R^t : \text{IF } x_1 \text{ is } A_{i1} \text{ AND } x_2 \text{ is } A_{i2} \ldots x_n \text{ is } A_{in}, \text{ THEN } y \text{ is } f_i \text{ where } i = 1, 2, 3, \ldots, n
\]  

(8)

\[
y^* = \frac{\sum_{i=1}^{n} \mu_i f_i}{\sum_{i=1}^{n} \mu_i} = \sum_{i=1}^{n} \mu_i f_i
\]  

(9)
The steps taken in the FMN Type 2 method are shown in Figure 2.

3. Results and discussions
The data used in this study are 20 eye fundus images, taken from the MESSIDOR database with the address http://mesddifor.crihan.fr where Mesdiffor is a research program funded by the 2004 French Ministry of Research and Defense TECHNO-VISI with image sharing used consisted of 10 fundus images for training process and 10 eye fundus images for the validation process. The size of the used image is 185 x 185 pixels and the format of the image used is .jpg. Examples of fundus images used in this study can be seen in Figure 3.
In this study, there are four steps that must be done, including pre-processing, image reduction, and detection of diabetic retinopathy. In the first stage, which is pre-processing, all the eye retinal fundus images used will be converted into grayscale images to obtain gray color, then the results of grayscale processing are processed again using histogram equalization to level the grayscale on the retinal fundus image of the eye. The results of the image processing stage can be seen in Figure 4, because the obtained results of image processing are still a large matrix data with a size of 185 x 185 and values that are in intervals of 0 to 255, then the second stage is to reduce the size of input data using Principal Components Analysis in order to obtain a new data size of 10 x 10. After the reduction process is complete, the results of the reduction in the retinal fundus image of the eye will be normalized for data scaling.

In the third stage, detection of diabetic retinopathy uses FMN type 2. The results of data normalization will be used as input for the FMN type 2 process. The results of the diagnosis using FMN type 2 with a number of trial levels of learning used such as 0.1203, 0.072, and 0.256. The accuracy of diagnosis percentage using FMN type 2 can be seen on Figure 5 and Table 1.
4. Conclusion
The purpose of this paper is to diagnose diabetic retinopathy on eye fundus image with Fuzzy Modelling Network Type 2 and Principal Component Analysis. The stages in the diagnosis of diabetic retinopathy are image processing, reduction of features and diagnosis process. The diagnosis of diabetic retinopathy shows that the system has been able to recognize image patterns well, with the accuracy is 80% using 0.256, 0.3037 and 0.6431 of learning rate.

Figure 5. The results of diagnosing diabetic retinopathy use FMN type 2

Table 1. Data on the diagnosis of diabetic retinopathy with a various learning rate

| Experiment to | Learning rate | MSE          | Iteration | Training | Validation |
|---------------|---------------|--------------|-----------|----------|------------|
| 1             | 0.1203        | $1.5288 \times 10^{-4}$ | 10        | 100%     | 40%        |
| 2             | 0.7007        | $1.4154 \times 10^{-4}$ | 10        | 90%      | 60%        |
| 3             | 0.7233        | $1.8345 \times 10^{-4}$ | 10        | 80%      | 70%        |
| 4             | 0.072         | $2.1219 \times 10^{-4}$ | 10        | 100%     | 70%        |
| 5             | 0.256         | $1.4827 \times 10^{-4}$ | 10        | 100%     | 80%        |
| 6             | 0.0683        | $2.0766 \times 10^{-4}$ | 10        | 80%      | 60%        |
| 7             | 0.9252        | $1.9164 \times 10^{-4}$ | 10        | 80%      | 50%        |
| 8             | 0.3037        | $1.8814 \times 10^{-4}$ | 10        | 100%     | 80%        |
| 9             | 0.6431        | $2.0335 \times 10^{-4}$ | 10        | 100%     | 80%        |
| 10            | 0.8311        | $1.7882 \times 10^{-4}$ | 10        | 100%     | 70%        |
References

[1] Guariguata L, Whiting D R, Hambleton I, Beagley J, Linnenkamp U, and Shaw J E 2014 Global Estimates of Diabetes Prevalence for 2013 and Projections for 2035. 137-149

[2] Nentwich M M and Ulbig M W 2015 Diabetic Retinopathy-Ocular Complications of Diabetes Mellitus. 6(3):489-499

[3] Lalfi A E, Eisa M, and Ahmed H 2013 Artificial Neural Networks in Medical Images for Diagnosis Heart Valve Diseases. International Jurnal of Computer Science. 10:1694-0814

[4] Kusumadewi S, and Hartati S 2006 Neuro-Fuzzy Integrasi Sistem Fuzzy dan Jaringan Syaraf. (edisi pertama). Yogyakarta: Graha Ilmu

[5] Budi S A, Suma’inna, and Maulana H. 2016. Pengenalan Citra Wajah sebagai Identifier Menggnakan Metode Principal Component Analysis (PCA). Jurnal Teknik Informatika. 9(2):166-175

[6] Kanan C and Cottrell G W 2012 Color to Grayscale: Does the Method Matter in Image Recognition?. 7(1)

[7] Dwipayana M, Arnia F, Musliyana Z 2017. Histogram Equalization smoothing for determining threshold accuracy on ancient document image binarization.

[8] Espirito S R 2012 Principal Component Analysis Applied to Digital Image Compression. 10(2): 135-139