Jurnal Ilmu Komputer dan Informasi (Journal of Computer Science and Information)
16/2 (2022), 141-149. DOI: http://dx.doi.org/10.21609/jiki.v16i2.1156

Biometric System for Person Authentication Using Retinal Vascular Branching Pattern

Diana Tri Susetianingtias, Sarifuddin Madenda, Rodiah, and Rini Arianty*

[1,4]Faculty of Computer Science and Information Technology , Gunadarma University, Depok, Indonesia
[2]Doctoral Program in Information Technology, Gunadarma University, Depok, Indonesia
[3]Faculty of Industrial Technology, Gunadarma University, Depok, Indonesia

diants@staff.gunadarma.ac.id, sarif@staff.gunadarma.ac.id, *rodiah@staff.gunadarma.ac.id*,
*rinia@staff.gunadarma.ac.id**

Abstract

The person's retina has its uniqueness that can be used as biometric recognition. The use of the retina as a marking feature in biometrics is more accurate in making calls, verification, and authentication. Retinal biometric characteristics are unique and difficult to manipulate, thus making the retinal biometric system one of the most reliable biometrics compared to other biometric characteristics. The retinal biometric system can be formed using extracted retinal vessels. The difficulty in extracting retinal vessels is a characteristic of retinal vessels. itself includes (central artery, central branch artery, central vein and central branch vein), the ratio of the thickness ratio between the different retinal arteries and veins (2:3), the location of the retinal artery and vein and the color. This complexity often results in errors in the retinal blood vessel extraction process, where not all blood vessel objects can be extracted properly which can reduce the accuracy of the retinal biometric system. This study will address the problem of extracting retinal vessels by proposing the use of an extraction method to produce truly unique retinal features to be included in the retinal biometric system by tracing all branches of the retinal vessels (consisting of: bifurcation, trifurcation and crossover).). The accuracy results show that 99.81% of the images were correctly detected. The blood pattern is obtained by doing extraction which includes the preprocessing stage and is continued by doing the blood extraction stage. This pattern extraction result is used as a unique pattern to be included in the feature vector of the biometric system in identifying person based on the retina.

Keywords: *Biometric, Blood Vessels, , Branches, Pattern, Retina.*

1. Introduction

Currently, individual identification is of great importance Individual identification is a very important part because many systems require legitimate users in access control [1] especially for systems that store valuable documents and important data. One of the current developed identification technologies is biometric feature-based identification technology [2]. The biometric identification system is a system that uses the characteristics of a person's biometric pattern [3] in identifying and recognizing. The currently developing biometric system-based individual identification technique is fingerprint, this is because fingerprints have about 40 unique characteristics, ergo that biometric fingerprints [4] can identify different individuals. Apart from fingerprints, one of the body parts that can be used as a biometric system for identification is the retina. The retina is a sensitive eye organ and functions in the ability to see, in addition to being used to see the retina is also can be used as identification because it has unique characteristics. In the retinal tissue [5], there are unique characteristics, namely the extraction results from the retinal image blood vessels and the branching pattern (furcation) in the retinal vessels, both arteries and veins. The branching pattern in the retinal vessels that are usually used as a characteristic feature of identifying individual retinas is bifurcation. Several problems occur in the extraction of retinal vessels which are used as a unique feature to form a retinal biometric system. Extraction errors in retinal blood vessel images will result in a mismatch between the pattern features correlated with the template image in the identification process to be wrong. This study forms a combination of branching blood vessels (bifurcation and trifurcation) and crossover on retinal fundus images. This combination is a series of unique combination numbers formed by the total number of branching points detected in the retinal fundus image vessels.

Research related to the method of extracting retinal blood vessels which is used as a feature to form a retinal biometric system was carried out by previous researchers. Retinal vascular feature extraction was performed using Fourier transform [6] and 2D Wavelet transform without preprocessing. This study implements the use of the Fourier transform by dividing the Fourier spectrum into several semicircles covering segments with a symmetrical area of the spectrum. Research [7] was using hit or miss transformation to obtain bifurcation and crossover points on retinal blood vessel images. Retinal biometric system feature extraction research was carried out [8] using preprocessing, where the output of this feature extraction process is a binary image of retinal blood vessel segmentation that has undergone various processes of eliminating non-vascular objects and improving image quality. The purpose of performing this image transformation is to increase the quantity of the existing image but still not eliminate the biometric features of the image. There was an error in the extraction carried out in this study where the central branch artery and vein were detected as non-blood vessels so that this object was removed and considered as noise. The feature extraction results are entered into the CNN model in forming the retinal biometric system [8]. Research to detect bifurcation and crossover was done by using the morphological operations of opening, closing, and watershed transformation. This study [9] counted interconnected pixels using a 3x3 mask. Each step of the mask will count the corresponding pixels. Pixel correspondence using a 3x3 mask cannot properly trace the extracted blood vessel images. A node pixel can be defined as a pixel that has two or more branches and corresponds to the midpoint of the mask as a crossover, so that at some pixels the crossover is detected as a bifurcation pixel. Retinal image vascular extraction by detecting the bifurcation point [10] was done by analyzing neighboring connectivity at the main node or junction point which is the meeting point of three or more pixels in the image of the candidate blood vessel. This study uses Depth First Search (DFS) [10]. The accuracy in this study did not reach 90% because the branching pixel search algorithm using retinal vessels using the DFS method cannot perform pixel searches on trifurcation and crossover considering that this method only searches one node in each image pixel from the far left and continues on to the leftmost node to the right. The central branch artery and central vein artery cannot be extracted properly [10]. Retinal feature extraction was performed [11] using a combination of a median filter and the first derivative of the Gaussian filter[12]. The median filter is used to eliminate noise in the form of information outside the retinal blood vessels (e.g. hard exudates, soft exudates, dot and blot hemorrhages). On non-vessel fundus image objects, objects such as: Optic disc and macula are still detected as vascular images so this can reduce the accuracy in extracting retinal vascular images. Research [13] performs automated vein extraction using Weighted Kernel Fuzzy C-Means (WKFCM) Clustering to perform feature extraction between vascular objects (foreground) and retinal image backgrounds. Research [13] implement the use of Dilation-Based Function (DBF) operator in extracting retinal blood vessels with branching. The use of dilation-based surgery on retinal blood vessel images results in removing some of the severed blood vessel objects so that the entire retinal blood vessel is not extracted properly.

This research will overcome the problems raised in previous studies [10] [11] [12] [13] by eliminating some errors in the process of extracting features of the retinal blood vessels as a feature that is truly unique to be included in the retinal biometric system by proposing an algorithm for the formation of branching combinations (bifurcation and trifurcation) and crossover through tracing of skeletal blood vessel images which in previous studies used node search operations with DFS [10] which cannot find trifurcation and crossover points. Another difficulty in extracting retinal blood vessels is that other objects in retinal fundus images are often extracted as part of blood vessels (for example : optic disc), thus can reduce the accuracy of identification in retinal biometric systems. It is necessary to apply the right method of extracting retinal blood vessels so as to be able to accurately detect blood vessel structures[14] to decrease False Rejection Rate in the retinal image identification process[15]. The unique pattern of retinal images can be identified by a supervised learning-based algorithm. The pattern of changing the value of the matrix from the retinal fundus image will be input into the biometric system to identify retinal features. This pattern will be associated as a unique characteristic in identifying a person based on the retina.

2. Method

Broadly speaking, the method proposed in this study consists of several process stages as can be seen in Figure 1.

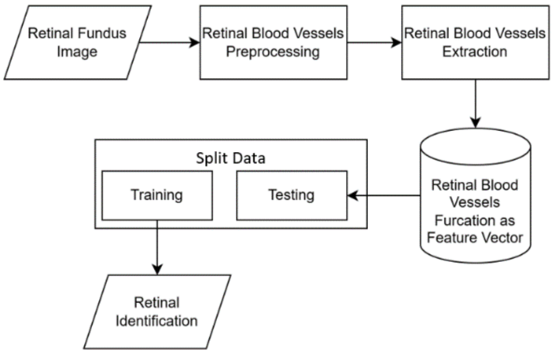

Fig. 1. Research Methodology

In this study, the data used by researchers was retinal fundus images as can be seen in Fig. 2. This study used retinal fundus images sourced from the DRIVE dataset [16] 565x584 in size and with the .tif file extension, a total of 10 individual retinal fundus images, where per 1 individual there are around 1800 images extracted from features using a 2-dimensional transformation technique. This study used a split data ratio of 8:2, where 80% of the images were used as training data in the amount of 14400 images and 20% were used as test data in the amount of 3600. Training at the branching point detected retinal blood vessel images using the multiclass ECOC model composed of SVM models using fitcecoc and testing using the Matlab confusionmat function. A 2-dimensional transformation technique was used in this study to increase the number of retinal fundus image samples per individual by performing a series of basic computer graphics operations [17] such as rotation, zoom, shift, cropping, and rotation which are used due to the limited number of image samples for each individual.

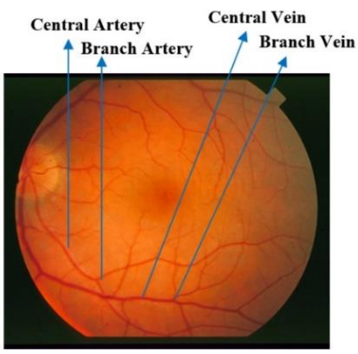

Fig. 2. Retinal Fundus Image [18]

2.1. Retinal Blood Vessels Preprocessing

Retinal fundus image vessels consist of arteries and veins. The artery is divided into a central artery and a central branch artery. Just like an artery, the vein is also divided into central veins and central branch veins which visually differ based on location, color, and thickness with a ratio of 2 [18]. Preprocessing is done before the feature extraction stage to analyze and determine the initial process that must be carried out on the image to provide optimal results in the next process.

Preprocessing in this study is divided into four processes: color channel extraction (analysis and selection of color components), green channel inversion, and optic disc elimination [19] as can be seen in Fig. 3.

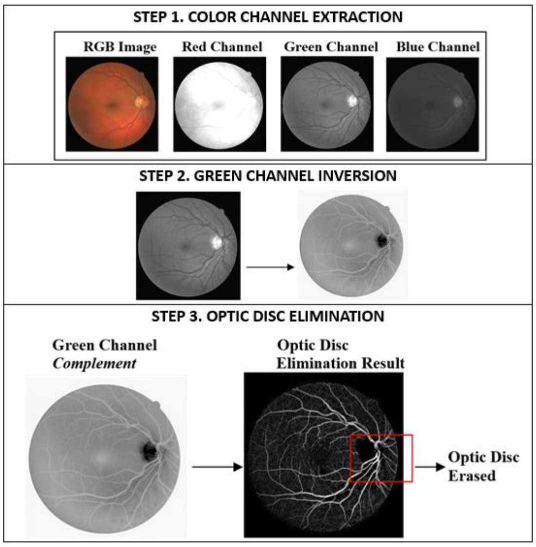

Fig. 3. Retinal Blood Vessels Preprocessing

Preprocessing in this study consists of 3 steps, namely:

Step 1:
Represents the retinal fundus image into three channels or RGB color channels: R channel is red (red channel), G channel is green (green channel) and B channel is blue (blue channel). Fig. 3. Step 1 shows an example of an RGB fundus image and an image for each channel, it looks like the Red channel is over saturated so that. This results in difficulties in the extraction process. In the blue channel it looks under saturated, the intensity of the blood vessels only looks a little different from the retina and in the green channel image it looks like it has the appropriate intensity and saturation so that the green channel is used in the next process.

Step 2:
The inverse operation is performed using Eq. (1) [20]:

$$comp = 255 - x \quad (1)$$

The comp variable is the intensity result. Variable x is the intensity value of the image at position x. This operation is performed to remove the retinal fundus image background to make it easier to separate blood vessel objects from the background.

Step 3:
Elimination of the optic disc is carried out where the optic disc is an object that is in the retinal fundus image and is part of a non-blood vessel. Elimination is carried out to minimize extraction errors that can occur due to the optic disc being recognized as part of a blood vessel. Simply put, elimination is done by applying the use of opening morphology using Eq.2 [20] [21] :

$$A \circ B = (A \Theta B) \oplus B \qquad (2)$$

Elimination is done by $A\Theta B$ erosion process and the dilation process uses operator $\oplus$ based on structuring elements that have a point of origin [20]. Formation of structuring elements is done using Eq. 3 [20] using variable p as the type of structuring element and parameter q.

2.2. Retinal Blood Vessels Extraction

After eliminating the optical disc object on the retinal fundus image, the next step is segmenting the retinal blood vessels. The segmentation was done by the researcher using the median filter operation on the image with the optic disc that had been eliminated. The median filter is used to reduce noise [22] in images such as the edge of the retina (boundary) to obtain only blood vessel objects. The filter median is based on the median value of the total number of surrounding pixels. The process of selecting the median value begins by sorting the neighboring pixel values, then selecting the median value. The results of the median filter operation are then continued by doing binarization [23] by determining the threshold value T which is the pixel mapping value that separates two pixels 0 (white) and 1 (black). Any pixel (x, y) that satisfies f (x, y)> T is the object pixel, that is, the veins and other pixels are the backgrounds [24]. The binarization result then is removed from the background using the first derivative of Gaussian [20] to obtain a segmented vascular candidate as shown in Fig. 4.

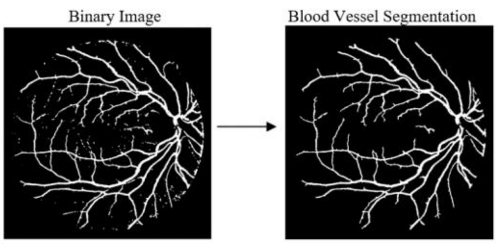

Fig. 4. Blood Vessel Segmentation

Retinal vascular segmentation is calculated using Eq. (3) :

$$g(x,y) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{d^2}{2\sigma^2}} \qquad (3)$$

Where is the distance of neighboring pixels from the central pixel, is the standard deviation of the distribution of the function with mean = 0. The value is calculated using the Eq. (4)[25] :

$$d = \sqrt{(x - x_c)^2 + (y - y_c)^2} \qquad (4)$$

Re-scaling Image Result of Extraction

The rescale process is conducted to reduce the computational load when training retinal features. The formation of feature vectors is obtained by converting the segmented retinal image into a numerical value so that at the original scale the retinal image results from blood vessel segmentation will form a large input vector size. The rescaling operation is performed based on the mean pixel value [26] in the segmented vein pattern which results in one average pixel value per segment with the average of each R-segment in the segmented image calculated using Eq. (5) [14]:

$$\bar{S}_R = \frac{\sum_{x=1}^{N}\sum_{y=1}^{M} I(x,y)}{(N+M)} \qquad (5)$$

Where is the average pixel value, *I (x, y)* Input image, *N* is the number of row pixels, and *M* is the number of column pixels.

The process of determining the furcation point (bifurcation and trifurcation) and the crossover of the blood vessel segmentation image is carried out using the following algorithm:

1. Reading the image results of the segmented blood vessels
2. Skeletonizing as shown in Fig. 5, to get a segmented image measuring 1 pixel. Skeletonization is done with the following algorithm : (1) Marking the border points to be deleted; (2) Deleting the points to be marked and change them to pixel 0; (3) Applying step 2 to the rest of the border points in step 1 that have not been deleted. Then adjust to all the conditions that must be met in step 2 by marking them for deletion and ; (4) Deleting marked points by converting them to number 0

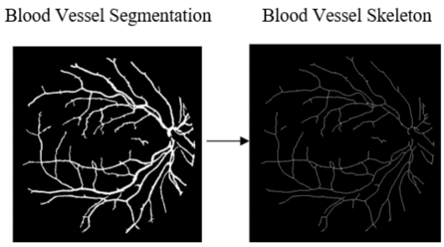

Fig. 5. Blood Vessels Skeletonizing

3. Determine the furcation point of the skeleton image as shown in Fig. 6.

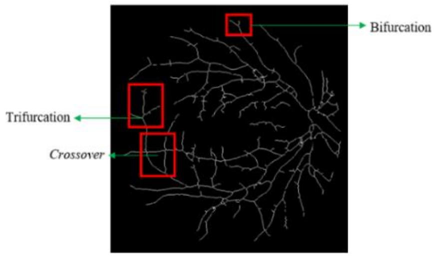

Fig. 6. The Process of Obtaining Skeleton Blood Vessels Image

- The process of detection of furcation points (bifurcation and trifurcation) and crossover is carried out using the following algorithm:
  1) Reading the skeletonized image [8]
  2) Invers the skeleton image
  3) Performing furcation point extraction with the following algorithm :
- Performing the filtering process using an NL filter (Matlab) to refine and sharpen the results of thinning the retinal blood vessels
- Determining the pixel rows and columns resulting from the thinning that has been enhanced with an NL filter
- Determination of the bifurcation point is done by determining the coordinates of the midpoint of the thinning blood vessels as the central pixel and labeled as the bifurcation point with the following conditions If there is a central pixel with a pixel value of one and two neighboring pixels worth one, the central pixel is a bifurcation. The search for the centroid point (central pixel) is carried out by the researcher using the second derivative of Gaussian using the Eq. (6) :

$$G(y,x) = e^{\frac{-x^2+y^2}{2\sigma^2}} \quad (6)$$

Where *G (x, y)* is the central pixel (centroid point), *x* and *y* are the rows and columns of the skeleton image and σ is the sigma value which is the radius filter to determine the size of the image matrix (for example, the image is 3x3, so 0.5 sigma is used)

- Determination of the trifurcation point is done by determining the coordinates of the midpoint of the thinning blood vessels as the central pixel and labeled as a trifurcation point provided that there is a pixel with one pixel value and three neighboring pixels are one
- Determination of the crossover point is carried out with the following conditions: If the central pixel has a cross pixel from the two lines leading to the central pixel is one then the pixel is a crossover. Determine the average distance between two neighboring lines using Eq. (7) [14]:

$$D = \frac{\sum_{i=1}^{x} \frac{a_i}{b_i} + \sum_{j=1}^{y} \frac{a_j}{b_j}}{x+y} \quad (7)$$

Where: *x* and *y* are the number of rows and columns in the skeleton image *I*, a_i The length of the *i*-th row, b_i the number of pixels is 1 in the *I* row, aj The length of the *j*-th column and b_j the number of pixels is 1 in the *j* column [27]. Table *I* is the logic of determining the furcation point. The process of The Process of Determining the Coordinates can be seen in Fig. 7

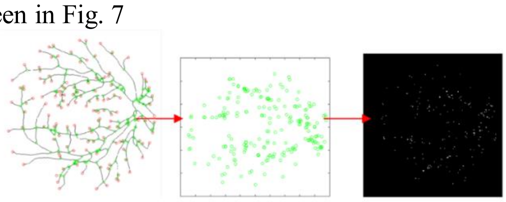

Fig. 7. The Process of Determining the Coordinates Bifurcation Point

2.3. Retinal Blood Vessels Furcation for Feature Vector

The next step after the furcation of the segmented blood vessels (bifurcation, trifurcation and crossover) is detected, is to count the number of bifurcation, trifurcation and crossover points using pseudocode [22]:

```
[Nx,Ny] = size(bifurcationPointsMedFilt);
WhitePixelCount = zeros(Nx,1)
```

The Number of bifurcation, trifurcation and crossover points into the feature vector is shown in Fig. 8.

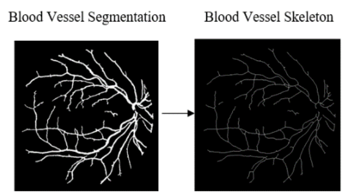

Fig. 8. The Process of Obtaining Skeleton Blood Vessels Image

2.4. Split Data

The next step after the furcation of the segmented blood vessels (bifurcation, trifurcation and crossover) is detected, is to count the number. Identification of features is used by the Support Vector Machine (SVM). This is done by researchers to see the results of the accuracy of retinal image identification and the length of computation time in identifying retinal images. SVM formation uses the parameter Error Correcting Output Codes (ECOC) [28] with one-vs-one (OVO) encoding. The ECOC parameter forms a binary label for each class to be formed. The binary label design on OVO ECOC has two types of indicators, namely +1 (positive class) and -1 (negative class), with the positive class always being above the negative class as in the OVO binary label design [29].

For example, the process of establishing a one-vs-one ECOC binary label design for each individual (example in 10 classes) is shown in Table 1

Table 1. Example of a Binary One-VS-One ECOC Label Design

Class	1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1	1
2	-1	0	0	0	0	0	0	0	0	0
3	0	-1	0	0	0	0	0	0	0	0
4	0	0	-1	0	0	0	0	0	0	0
5	0	0	0	-1	0	0	0	0	0	0
6	0	0	0	0	-1	0	0	0	0	0
7	0	0	0	0	0	-1	0	0	0	0
8	0	0	0	0	0	0	-1	0	0	0
9	0	0	0	0	0	0	0	-1	0	0
10	0	0	0	0	0	0	0	0	-1	0

In classifier 1, the branching feature has a value of 82636 cells to store the results of feature extraction. The use of cellssize is used to speed up the data training process. The training and testing process uses a ratio of 8: 2 out of a total of 18000 images resulting from the transformation with details on the training set used as much as 80% or 14400 retinal vessel images and in the validation set process used as much as 20% or 3600 retinal blood vessel images. The results of the formation of the model will produce an accuracy value of the training data process and also the data validation process using the confusion matrix. The final stage of this research is the process of identifying the retinal biometric system using test data totaling 10 retinal vascular images per individual. The high level of accuracy of the model when training the data greatly influences the performance evaluation results of the model in identifying individuals based on the retinal biometric system [30].

3. Result and Discussion

The size of the test image used varies with 8 bits per color channel with the Portable Pix Map (ppm) and .tif formats.

3.1. Retinal Blood Vessels Extraction Result

Segmentation is performed on images that have been eliminated by optical disc using a median filter. The results of the segmentation with the median filter still have a lot of noise. The edge of the retinal fundus image was still detected as noise, so a second segmentation was carried out using first derivative of Gaussian [27] to get the segmented image without noise as can be seen in Fig. 9.

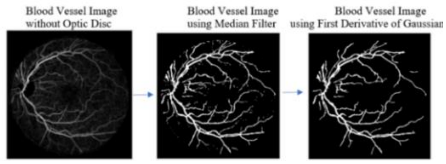

Fig. 9. Blood Vessels Segmentation Results

3.2. Retinal Vein Furcation Extraction Result

After obtaining the image of the retinal blood vessel segmentation, the next process is skeletonization to obtain a one-pixel image of blood vessels that will be used to determine the furcation points (bifurcation, trifurcation) and crossover of the segmented blood vessel image. The results of furcation point detection can be seen in Fig. 10

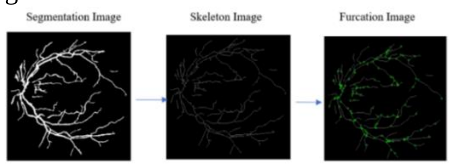

Fig. 10. Extraction of Blood Vessels with Furcation Features

Based on the results of determining the number of branching points, the combination number of furcation feature extraction in the form of the number of furcation detected as could be seen on Fig.11.

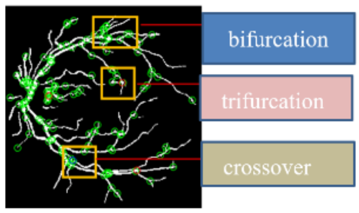

Fig. 11. Blood Vessels Extraction Results

The number of extracted bifurcation, trifurcation and crossover points will be included in the feature vector as Fig. 12 for identification

Retinal blood vessels consisting of veins and arteries, where the arteries are divided into central arteries and central branch arteries as well as veins which are divided into central veins and central branch veins which visually have differences based on location, color and thickness with a ratio of 2 :3. The complexity of the features of the retinal blood vessels often results in errors in the extraction of blood vessels where all objects in the blood vessels are not extracted properly [13][14][15].

The complexity of the features in the retinal blood vessels often results in vascular extraction errors where all objects in the blood vessels are not extracted properly.

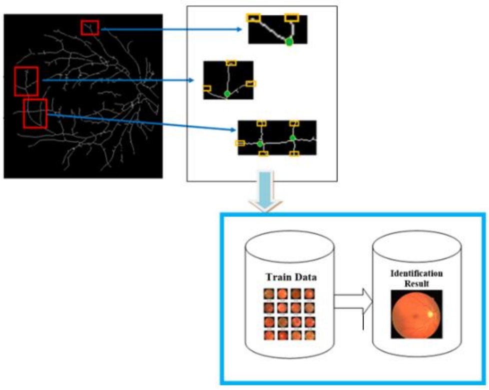

Fig. 12. Vector Feature Combination of Retinal Blood Vessels Furcation

3.3. Identification Result

Based on the results of the loss function graph contained in Fig. 13 shows that the training loss movement is very good with a steady decrease in each iteration.

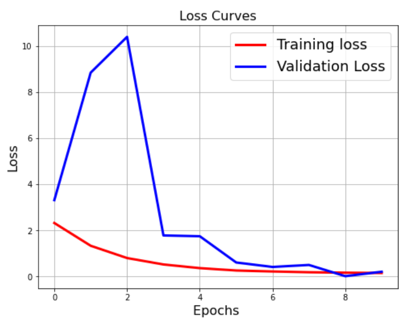

Fig. 13. Testing Loss Function Graph

In testing the loss, the graphic movement tends to fluctuate with a significant increase in the 1st and 2nd iterations, but after that the movement decreases slowly until it becomes almost equal or even exceeds the training loss. This shows that the identification accuracy of the retinal image is good as can be seen with a percentage of 99.81% success in making identification as can be seen in the confusion matrix Fig. 14.

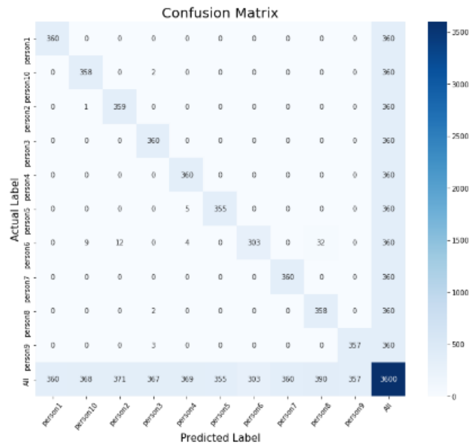

Fig. 14. Confusion Matrix Identification Result

Fig. 14 shows that the identification results of the individual retinal biometric system were carried out very well, resulting in an identification of 99.81%. This is because the results of the accuracy value at the time of model formation are very high. The percentage loss value of 0.19% on average lies in the Person6 image because in the results of the confusion matrix it can be seen that the distribution of identification data on Person6 has experienced some identification errors as a result of some retinal images in Person6 there is lower saturation in some training images compared to data in other images.

4. Conclusion

Based on the results of trials on the retinal blood vessel extraction algorithm, the furcation point detection algorithm as a retinal biometric feature, and the results of trials on the biometric recognition system that has been developed, it can be concluded: extract retinal blood vessels well. The furcation point determination algorithm can detect all bifurcation, trifurcation and crossover points in the retinal vessels. The number of points for each furcation feature is used as a feature vector in the retinal image identification process. The retinal vein furcation feature extraction algorithm as the basis for individual recognition and the distance between the furcation points of the retinal blood vessels was successful in identifying retinal images by testing using the SVM algorithm resulting in an accuracy rate of success reaching

99.81%. The error of 0.19% in the identification of the retinal blood vessel images is due to the low saturation of some of the training images. This can be overcome by adding variations to the training data and test data.

Research can further develop the training process using other machine learning methods with low computation and high speed so as to accelerate the process of identifying retinal images in recognizing individuals based on retinal features. Retinal image clustering is based on the number of detected dots intervals so as to speed up the retrieval process of retinal image information without having to search the entire image.

Acknowledgement

Thank you to the Directorate of Research, Technology and Community Service, Directorate General of Higher Education, Research and Technology Ministry of Education, Culture, Research and Technology According to the Research Contract with LLDIKTI 3 Number: 456/LL3/AK.04/2022. Gunadarma University Research Institute for the smooth implementation of this research activity.

References

[1] S. A. Abdulrahman and B. Alhayani, “A comprehensive survey on the biometric systems based on physiological and behavioural characteristics,” *Mater. Today Proc.*, no. July, 2021, doi: 10.1016/j.matpr.2021.07.005.

[2] O. A. Ayomide *et al.*, “Optimization Of An Identity Access control System Using Biometric Techniques,” *Int. J. Progress. Sci. Technol. (IJPSAT*, vol. 27, no. 2, pp. 647–653, 2021, [Online]. Available: http://ijpsat.ijsht-journals.org

[3] S. Albalawi, L. Alshahrani, N. Albalawi, R. Kilabi, and A. Alhakamy, “A Comprehensive Overview on Biometric Authentication Systems using Artificial Intelligence Techniques,” *Int. J. Adv. Comput. Sci. Appl.*, vol. 13, no. 4, pp. 782–791, 2022, doi: 10.14569/IJACSA.2022.0130491.

[4] P. K. Bose and M. J. Kabir, “Fingerprint: A Unique and Reliable Method for Identification,” *J. Enam Med. Coll.*, vol. 7, no. 1, pp. 29–34, 2017, doi: 10.3329/jemc.v7i1.30748.

[5] M. P. Gupta, A. A. Herzlich, T. Sauer, and C. C. Chan, “Retinal anatomy and pathology,” *Dev. Ophthalmol.*, vol. 55, no. October, pp. 7–17, 2015, doi: 10.1159/000431128.

[6] A. A. Abdulsahib, M. A. Mahmoud, H. Aris, S. S. Gunasekaran, and M. A. Mohammed, “An Automated Image Segmentation and Useful Feature Extraction Algorithm for Retinal Blood Vessels in Fundus Images,” *Electron.*, vol. 11, no. 9, 2022, doi: 10.3390/electronics11091295.

[7] T. H. Betaouaf, E. Decencière, and A. Bessaid, “Automatic biometric verification algorithm based on the bifurcation points and crossovers of the retinal vasculature branches,” *Int. J. Biomed. Eng. Technol.*, vol. 32, no. 1, pp. 66–82, 2020, doi: 10.1504/IJBET.2020.104677.

[8] Rodiah, S. Madenda, D. T. Susetianingtias, Fitrianingsih, D. Adlina, and R. Arianty, “Image processing, pattern recognition retinal biometric identification using convolutional neural network,” *Comput. Opt.*, vol. 45, no. 6, pp. 865–872, 2021, doi: 10.18287/2412-6179-CO-890.

[9] G. Wang, Y. Huang, K. Ma, Z. Duan, and Z. Luo, “Automatic vessel crossing and bifurcation detection based on multi-attention network vessel segmentation and directed graph search,” vol. 155, no. October 2022, 2023, doi: 10.1016/j.compbiomed.2023.106647.

[10] Y. Ma, Z. Zhu, Z. Dong, T. Shen, and M. Sun, “Multichannel Retinal Blood Vessel Segmentation Based on the Combination of Matched Filter and U-Net Network,” vol. 2021, 2021.

[11] M. Maison, U. Jambi, T. M. Lestari, and U. Riau, “Retinal Blood Vessel Segmentation using Gaussian Filter Retinal Blood Vessel Segmentation using Gaussian Filter,” no. June 2020, 2019, doi: 10.1088/1742-6596/1376/1/012023.

[12] H. K. Putra and B. Suprihatin, “Retinal Blood Vessel Extraction Using a New Enhancement Technique of Modified Convolution Filters and Sauvola Thresholding,” vol. 2350006, pp. 1–23, 2022, doi: 10.1142/S0219467823500067.

[13] C. Clustering, D. Functions, and K. Wisaeng, “Retinal Blood-Vessel Extraction Using Weighted Kernel Fuzzy,” 2023.

[14] D. T. Susetianingtias, H. S. Suryadi, S. Madenda, Rodiah, and Fitrianingsih, “Blood vessel extraction and bifurcations detection using hessian matrix of gaussian and euclidian distance,” *J. Theor. Appl. Inf. Technol.*, vol. 95, no. 15, pp. 3471–3478, 2017.

[15] I. Tot, J. Bajčetić, B. Jovanović, M. Trikoš, D. Bogićević, and T. Gajić, “Biometric standards and methods,” *Vojnoteh. Glas.*, vol. 69, no. 4, pp. 963–977, 2021, doi: 10.5937/vojtehg69-32296.

[16] Larxel, “No Title,” 2020. https://www.kaggle.com/datasets/andrewmvd/drive-digital-retinal-images-for-vessel-extraction

[17] F. A. Jassim and F. H. Altaani, “Hybridization of Otsu Method and Median Filter for Color Image Segmentation,” no. October, 2014.

[18] Á. S. Hervella, J. Rouco, J. Novo, and M. Ortega, “Learning the retinal anatomy from scarce annotated data using self-supervised multimodal reconstruction,” *Appl. Soft Comput. J.*, vol. 91, p. 106210, 2020, doi: 10.1016/j.asoc.2020.106210.

[19] L. Laurik-feuerstein, R. Sapahia, and D. C. Debuc, “The assessment of fundus image quality labeling reliability among graders with different backgrounds,” pp. 1–11, 2022, doi: 10.1371/journal.pone.0271156.

[20] R. C. Gonzalez and R. E. Woods, *Digital Image Processing, 4e*.

[21] R. Dastres and M. Soori, “Advanced Image Processing Systems,” no. March, 2021.

[22] S. Dash, S. Verma, S. Kim, J. Shafi, and M. F. Ijaz, “Analysis of Vessel Segmentation Based on Various Enhancement Techniques for Improvement of Vessel Intensity Profile,” vol. 2022, 2022.

[23] R. Heriansyah and W. M. Utomo, “Performance Evaluation of Digital Image Processing by Using Scilab,” vol. 9, no. 2, pp. 239–247, 2021.

[24] D. T. Susetianingtias, S. Madenda, Fitrianingsih, D. Adlina, Rodiah, and R. Arianty, “Retinal blood vessel extraction using wavelet decomposition,” *Int. J. Adv. Comput. Sci. Appl.*, vol. 11, no. 4, pp. 351–355, 2020, doi: 10.14569/IJACSA.2020.0110448.

[25] P. Robinson, “Computer Graphics & Image Processing Peter Robinson Sixteen lectures for Part IB CST Four supervisions suggested Two exam questions on Paper 4 What are Computer Graphics & Image Processing ?,” vol. 2014, no. c, pp. 1996–2014, 2014.

[26] S. Yuan, “Image Processing Method Based on FGCA and Artificial,” vol. 2022, 2022.

[27] D. M. Abdulsahib and H. F. Jaafar, “Automated Approach for Extraction of Retinal Blood Vessels,” *IOP Conf. Ser.*

Mater. Sci. Eng., vol. 978, no. 1, pp. 1–12, 2020, doi: 10.1088/1757-899X/978/1/012037.

[28] N. Ullah *et al.*, "Diabetic Retinopathy Detection Using Genetic Algorithm-Based CNN Features and Error Correction Output Code SVM Framework Classification Model," vol. 2022, 2022.

[29] W. K. Mutlag, S. K. Ali, Z. M. Aydam, and B. H. Taher, "Feature Extraction Methods: A Review," *J. Phys. Conf. Ser.*, vol. 1591, no. 1, pp. 1–10, 2020, doi: 10.1088/1742-6596/1591/1/012028.

[30] M. S. A. Malik, Q. Zahra, I. U. Khan, M. Awais, and G. Qiao, "An Efficient Retinal Vessels Biometric Recognition System by Using Multi-Scale Local Binary Pattern Descriptor," *J. Med. Imaging Heal. Informatics*, vol. 10, no. 10, pp. 2481–2489, 2020, doi: 10.1166/jmihi.2020.3180.