Classification of diabetic retinopathy using fractal dimension analysis of eye fundus image

by Dwi Juniati

Classification of Diabetic Retinopathy using Fractal Dimension Analysis of Eye Fundus Image

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Abstract. Diabetes Mellitus (DM) is a metabolic disorder when pancreas produce inadequate insulin or a condition when body resist insulin action, so the blood glucose level is high. One of the most common complications of diabetes mellitus is diabetic retinopathy which can lead to a vision problem. Diabetic retinopathy can be recognized by an abnormality in eye fundus.Those abnormalities are characterized by microaneurysms, hemorrhage, hard exudate, cotton wool spots, and venous's changes. The diabetic retinopathy is classified depends on the conditions of abnormality in eye fundus, that is grade 1 if there is a microaneurysm only in the eye fundus ; grade 2, if there are a microaneurysm and a hemorrhage in eye fundus; and grade 3: if there are microaneurysm, hemorrhage, and neovascularization in the eye fundus. This study proposed a method and a process of eye fundus image to classify of diabetic retinopathy using fractal analysis and K-Nearest Neighbor (KNN). The first phase was image segmentation process using green channel, CLAHE, morphological opening, matched filter, masking, and morphological opening binary image. After segmentation process, its fractal dimension was calculated using box-counting method and the values of fractal dimension were analyzed to make a classification of diabetic retinopathy. Tests carried out by used k-fold cross validation method with k=5. In each test used 10 different grade K of KNN. The accuracy of the result of this method is 89,17% with K=3 or K=4 , it was the best results than others K value. Based on this results, it can be concluded that the classification of diabetic retinopathy using fractal analysis and KNN had a good performance.

INTRODUCTION

Diabetes Mellitus (DM) is a metabolic disorder when pancreas produce inadequate insulin or a condition when body resist insulin action, so the blood glucose level is high. According to the International Diabetes Federation (IDF), people with diabetes in 2030 will reach 592 million people [4]. World Health Organization (WHO) reported that Indonesia is in fourth with the highest number of patients with DM. It is estimated that in 2020 will reach 21,3 million people [11]. One of the most common complications of diabetes mellitus is diabetic retinopathy which can lead to vision problems. [6]. Epistemological research in the United States, Australia, Europe, and Asia estimate that in 2030 people with diabetic retinopathy will increase to 154,9 million people [12]. Based on The DiabCare Asia 2008 study, 42% of diabetic's patients in Indonesia suffered retinopathy diabetic [10]. Diabetic retinopathy is caused by pathological changes in the blood vessels which nourish the retina. The level of Diabetic retinopathy can be recognized by an abnormality in eye fundus, such as microaneurysms, hemorrhage, hard exudate, cotton wool spots, and venous changes [3]. A classification of diabetic retinopathy level can be found at messidor database. The Messidor database, which contains hundreds of eye fundus images, has been publicly distributed since 2008. It was created by the Messidor project in order to evaluate automatic lesion segmentation and diabetic retinopathy grading methods. The grade 0 for normal fundus, its means there is no characteristic of diabetic retinopathy, grade 1 if there is a microaneurysm only in the eye fundus; grade 2, if there are a microaneurysm and a hemorrhage in eye fundus; and grade 3: if there are microaneurysm, hemorrhage, and neovascularization in the eye fundus [8].

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Identification of abnormality in eye fundus can be done by examining fundus image photography (capturing fundus image using a digital fundus camera). Seoud et al [9] propose a first automatic grading system for diabetic retinopathy. They used a red lesion detection to generate a lesion probability map. The latter was represented by 35 features combining location, size and probability information for classification. The proposed system achieved a classification accuracy of 74.1%. In this study, we proposed another method and processing of an eye fundus image using fractal dimension analysis.

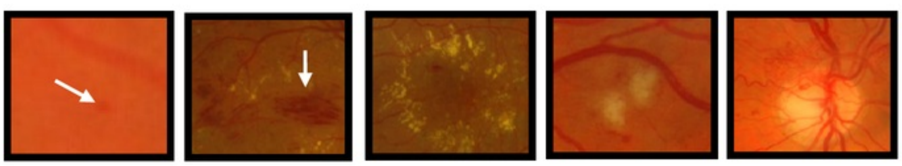
The limited ophthalmologist in Indonesia implies medical treatment and first aid of diabetic retinopathy are not optimal. General practitioners were spread in Indonesia hold an important role in the early detection of diabetic retinopathy. If the general practitioners have a tool or a method to help them to diagnose diabetic retinopathy, they could refer the patient immediately to the ophthamologist to be treated. So, the method is proposed here is an initial step to realize that purpose.

The structure of blood vessels in the retina has a self- similarity characteristic which means have similar shapes on a different scale. This is one of the characteristics of a fractal object. Therefore, a calculation method of fractal dimension can be applied to retinal blood vessel. In this study, a box-counting method was used to calculate the fractal dimension of retina blood vessels. Box-counting method effectively is used to calculate the dimensions of an object with an irregular shape. In addition, a box-counting method is very popular because it can be used in many situations including the characteristic of vessels in a retinal fundus. The analysis of fractal dimension of vessels in retina fundus images is useful to recognize the normality of retina or the indication of diabetic retinopathy.

DIABETIC RETINOPATHY AND THE PROCESSING FOR CITRA

Diabetic Retinopathy

Diabetic retinopathy is a retina abnormality which be found in diabetes mellitus patients. Diabetic retinopathy occurs when the increased glucose level in the blood damages the capillaries, which nourish the retina. The damage makes the capillary leak so blood and fluid input on the retina. The visual of this leakage are features, such as microaneurysms, hemorrhage, hard exudate, cotton wool spots, and venous's changes [2]. To identify that abnormality can be done by a fundus image photography examination (capturing fundus image using digital fundus camera). The image of abnormalities fundus in diabetic retinopathy can be seen in Fig. 1.



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

FIGURE 1. Abnormalities fundus of diabetic retinopathy: (a) microaneurysms (marked with an arrow), (b) hemorrhage (marked with an arrow), (c) hard exudate, (d) cotton wool spots, and (e) neovascularization.

Green Channel

RGB image is a digital image consisting of three channels, namely Red (R), Green (G), and Blue(B). Each pixel in RGB image is a combination of three basic colors of red, green, and blue. In this study, green channel was extracted from RGB image because green channel shows high intensity as compared to red and blue channels, as mentioned by Rajput, et al [10] and it can be seen by following pictures.

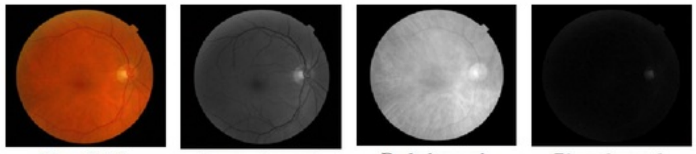


FIGURE 2. RGB image, and its green channel, red channel, blue channel

CLAHE

CLAHE (Contrast Limited Adaptive Histogram Equalization) is used for enhancing a quality of image. CLAHE is a development of AHE (Adaptive Histogram Equalization). The problem on AHE (increasing contrast) can be handle with CLAHE by providing limit value on the histogram. This limit value is called the clip limit which is the maximum height of a histogram. Calculation of clip limit is defined as follow:

$$\beta = \frac{M}{L}\left(1 + \frac{\alpha}{100}\left(s_{max} - 1\right)\right) \tag{1}$$

Where M is region size, L is a grayscale value (255) and α = clip factor (value between 0-100).

Convolution

Convolution is a technique for improved image quality, image smoothing, noise removal, and sharpening of the image by replacing the pixel value with a number of corresponding value but does not resize the image. The formed of convolution with discrete function was used defined as follow:

$$h(x,y) = f(x,y) * g(x,y) \tag{2}$$

$$h(x,y) = \sum_{a=-\infty}^{\infty} \sum_{a=-\infty}^{\infty} f(a,b) \cdot g(x-a, y-b)$$

Thresholding

Thresholding method is used to change from grayscale image to binary image that can be used to differentiate between an object from the background. Thresholding technique can be done by selecting a threshold value T. It is defined as:

$$T = Y\left[x, y, p(x,y), f(x,y)\right] \tag{3}$$

Where $p(x, y)$ is a pixel value in a certain point and $f(x, y)$ is the intensity of pixel (x,y). Furthermore, result of thresholding is divided into two parts which are defined as:

$$g(x, y) = 1 \; jika \; f(x, y) > T \tag{4}$$

$$g(x, y) = 0 \; jika \; f(x, y) \le T \tag{5}$$

The value 1 of a pixel, indicates the object, whereas value 0 of a pixel indicates the background.

Matched Filter

Matched filter is a template matching algorithm to detect blood vessels in a retina. The branching of blood vessels is similar with the gaussian curve so gaussian filter shapes are used in the detection of blood vessels. The matched filter is defined as:

$$f(x,y)=\frac{1}{\sqrt{2\pi\sigma}}\exp\left(\frac{-x^2}{2\sigma^2}\right)-m, \quad |x|\le t\cdot\sigma, |y|\le L/2 \tag{6}$$

where σ is a scale of a filter

$$m=\left(\int_{-t\sigma}^{t\sigma}\frac{1}{\sqrt{2\pi\sigma}}\exp\left(\frac{-x^2}{2\sigma^2}\right)dx\right)\Big/(2t\sigma) \tag{7}$$

m is used to normalize the mean value of filter to be 0, so that after filtering the smooth background can be removed. L is the length of neighborhood pixel along y-axis, t is a constant equal 3. The parameter of L depends upon s. Whereas s decreases L is also decreased. Then f(x,y) is rotated at an angle θ with different orientations.

$$f^{\theta}(x',y')=f(x,y) \tag{8}$$

With $x'=x\cos\theta+y\sin\theta$, $y'=y\cos\theta-x\sin\theta$

Response matched filter image is obtained from a convolution of a morphological opening image and matched filter kernel that has been rotating with a different orientation.

Masking

Masking is a separation technique that separates one object from the others by grouping the spectral value on digital data, and will generate a new digital value with binary value. The purpose of used masking's method is the background will be in black and is not counted as an object.

Morphological Opening

The morphological opening is useful to have a smoother object and remove areas do not contain Structuring Element (SE). SE is a sub-image which is examined the characteristic. Morphological opening is an erosion that followed by dilation. Morphological opening is defined as follows:

$$A\circ B=(A\theta B)\oplus B \tag{9}$$

Where A is the initial object which is processed and B is SE.

FRACTAL ANALYSIS

Fractal Dimension

Fractal was firstly introduced by Benoit Mandelbrot (French-American mathematician) around 1975 in his book entitled "Les Objects Fractal". Fractal is about irregular sets or non-smooth functions. The characteristic of a fractal is self similarity, self affinity, self inversion, and self squaring. Self similarity means that a fractal shapes is similar at different scale. Self affinity means that a fractal shapes composed of parts to be integrated with each other. Self inversion means a fractal shapes that an inverted arrangement of the other arrangement. And self squaring means a fractal shapes is gotten by increase in the complex's level of previous fractal shapes [7].

Fractal dimension is different with Euclidean dimension, where dimension of a point is zero, dimension of a line is one, dimension of a rectangular area is 2, and dimension of a cube is 3. Fractal dimension can be a non-integer number, for example fractal dimension of Coastline of Britain is 1,2. Fractal dimension is very important because it can associate with real data. In addition to measure the dimension of a coastline, fractal can also be used to measure dimension of cloud to predict rain, dimension of ground to determine the fertility of the soil, dimension of dust to determine the cleanliness of the air, and others. One of fractal dimension calculation methods is box-counting method. Box-counting is an effective method to calculate dimension of an object with irregular shapes. The principle of this method is cover the image or the object with a grid, and then count how many boxes of the grid are covering the image. Then, do the same thing but using a finer grid with smaller boxes. Calculating the fractal dimension using box-counting is defined as follow:

$$D = \frac{\log(N(r))}{\log(1/r)} \tag{10}$$

Where N(r) is the number of boxes with size r that cover the image. Here is an algorithm for finding the value of fractal dimension using box-counting [1]:

1. Covering the object area with square boxes with size r. The value of r change from 1 to $(½)^n$, with n=0,1,2. Count the value of N(r)
2. Count the value of log(1/r) and log(N(r))
3. Make a straight line of the data (x(n), y(n)) with x(n) indicate the values of log(1/r) and y(n) : the value of log(N(r))
4. Calculating the slope α of the straight line of the step 4. Then -α be a fractal dimension of the object.

K-Nearest Neighbor (KNN)

K-Nearest Neighbor (KNN) is a classification method based on learning data that has a close distance to the object. To determine the distance between two points are used euclidean distance formula, defined as follows:

$$D(x, y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2} \tag{12}$$

Where D is the distance between a point on testing data (x) and a point of training data (y) that will be classified. Here, the algorithm of KNN method:

1. Start
2. Determine the number of nearest neighbors K
3. Calculating the distance between testing data and training data using euclidean distance formula
4. Sorting the data based from the smallest euclidean distance
5. Specifies the group of testing data according to majority label of the K
6. Stop.

METHODOLOGY

Database

In this study, the data of eye fundus image was chosen from the messidor database that was accessed at *http://messidor.crihan.fr/index-en.php. and* randomly selected. There were 120 fundus images consists of four classes and there were 30 images in the each class. Four classes were used in this study correspond with the grade of retinopathy diabetic in the messidor database. The grouping of classes in the messidor database namely: grade 0 for normal fundus, its means there is no characteristic of diabetic retinopathy; grade 1 if there is a microaneurysm only in the fundus image; grade 2, if there are a microaneurysm and a hemorrhage in fundus image; and grade 3: there are microaneurysm, hemorrhage, and neovascularization in fundus image.

Implementation

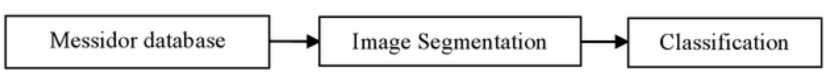


FIGURE 3. Implementation plot

The implementation begins with segmentation process to change the image to be a binary image by separating the blood vessel from the background. After segmentation process, then calculate the value of fractal dimension by using box-counting method. The fractal dimensions of all eye fundus images were used for classification the grade of diabetic retinopathy (grade 0,1,2,3).

Image Segmentation

Here is the flowchart of the process of image segmentation :

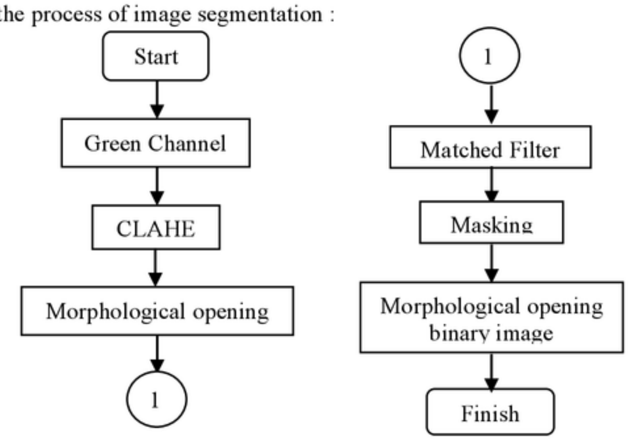


FIGURE 4. Flowchart of segmentation process

RGB images of messidor database were extracted to be in green channel images, because the green channel has a nice reflection of light. Furthermore, CLAHE process was done for enhancing image quality. Then continued by a morphological opening process to smooth the line of a blood vessel. The next process was matched filter and then thresholding to obtain a binary image that will separate between blood vessels from the background. After thresholding process, masked the image to remove the edge of retina. Last process was a morphological opening for binary image to smooth the line and remove noise on the image result of masking to have a significant blood vessel image.

Fractal dimension calculated

In this stage, the fractal dimension of the result of all image segmentation process were computed using a box-counting method.

Classification

Classification method was used in this study is a K-Nearest Neighbor (KNN). The input of KNN were the fractal dimension values of each image that was calculated. For testing a classification performance was used k-fold cross validation method with k=5. In this method, the data was divided randomly into 5 sections with equal size. In each experiment, 4 partitions were used for training data and the other one for testing data. This process was repeated five times so that each partition was used to test exactly one time. After classification, to know the accuracy of the system is calculated by the following equation:

$$Accuracy = \frac{Amount\ of\ correct\ data}{Amount\ of\ all\ data} \times 100\% \quad (13)$$

RESULT

Image Segmentation

The process of image segmentation was described on methodology. The purpose of the segmentation process was to change RGB images to binary images with black for background and white for object/blood vessels. Image segmentation was performed on 120 images which were divided into 4 classes with 30 images in every class. The result image of every process for every class described below with (a). the initial image from messidor database, (b). green channel image, (c). image of CLAHE process, (d). image after morphological opening, (e). image after matched filter, (f). image result of masking and (g). segmentation image.

Class 0

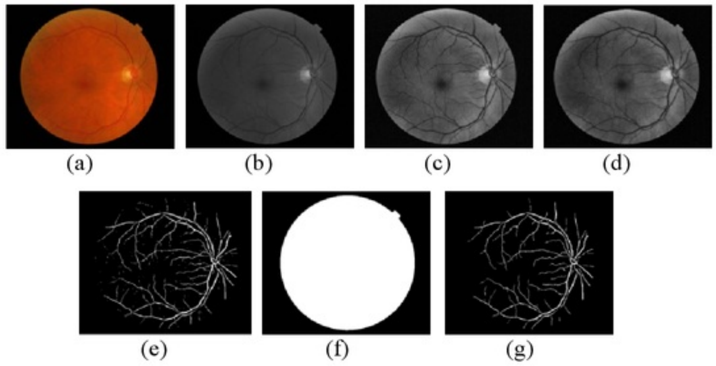


FIGURE 5. Segmentation process for normal fundus image

Class 1

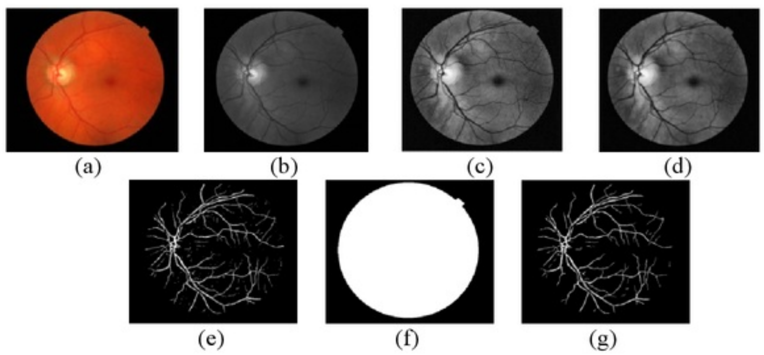


FIGURE 6. Segmentation process for diabetic retinopathy image class 1

Class 2

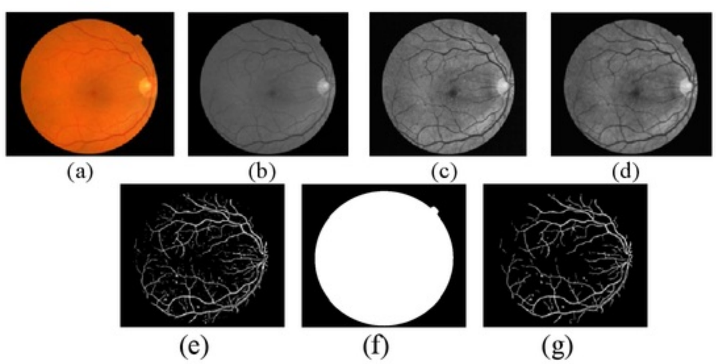


FIGURE 7. Segmentation process for diabetic retinopathy image class 2

Class 3

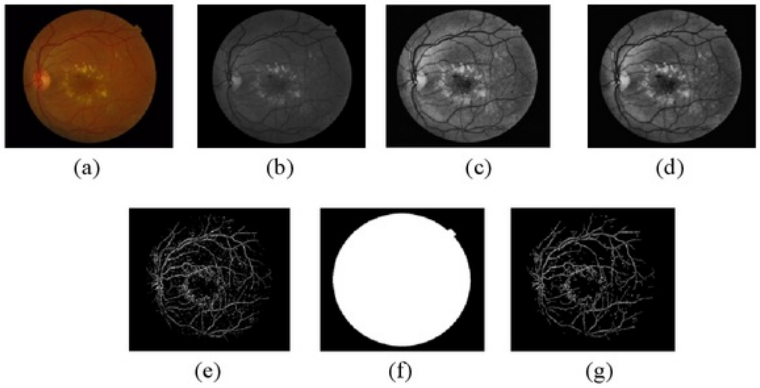


FIGURE 8. Segmentation process for diabetic retinopathy image class 3

Classification

After segmentation process, the calculation of fractal dimension for each image using a box-counting method was done. This was the example of fractal dimension calculation by box-counting method of image "20051110_ 38644_0400_PP" (normal class/grade 0):

1. Determining value of r and calculating value of N(r)
2. Calculating value of log(1/r) and log(N(r)).

Table 1. Value of r, N(r), log(1/r) and log(N(r))

r	**N(r)**	**log(1/r)**	**log(N(r))**
1	1	0	0
2	2	-0,301	0,301
4	6	-0,602	0,778
8	16	-0,903	1,204
16	45	-1,204	1,653
32	141	-1,505	2,149
64	378	-1,806	2,577
128	933	-2,107	2,969
256	2188	-2,408	3,340
512	5295	-2,709	3,723

3. Make a straight line from value of log(1/r) and log(N(r))

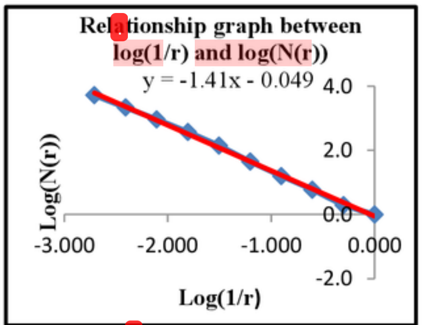


FIGURE 9. Relationship graph between value of log(1/r) and log(N(r)) on "20051110_ 38644 _0400_PP" image (class 0).

4. Calculating α the slope of straight line.
   α is a slope, fractal dimension is $-\alpha$.
   $\alpha = -1{,}41$

   Thus, fractal dimension of "2005 1110_38644_0400_PP" image is 1,41.

Henceforth, the calculation of the value of the fractal dimension was done with matlab. After analyzing all images, the mean of fractal dimension of every class was calculated.. Table 2 shows their values corresponding to each class of the considered images. It could be seen that the higher stage of illness the higher mean value of fractal dimension.

Table 2. Mean value of each class

Fractal dimension	**Class 0**	**Class 1**	**Class 2**	**Class 3**
Mean	1,3977	1,4496	1,4749	1,5344

After the value of all fractal dimension images were obtained, the classification using KNN algorithm. Testing result of classification used k-fold cross validation with k=5 as described in methodology. The classification of KNN were calculated with different values of K.

Table 3. accuracy from different value of K

Nilai K	Error	Akurasi (%)
K=1	0,1667	83,33
K=2	0,1667	83,33
K=3	0,1083	89,17
K=4	0,1083	89,17
K=5	0,1250	87,50
K=6	0,1167	88,33
K=7	0,1667	88,33
K=8	0,1750	82,50
K=9	0,1667	83,33
K=10	0,1583	84,17

Best accuracy value was obtained with K=3 and K=4 that have same value is equal 89,17%. The result show that fractal analysis was useful to classify diabetic retinopathy.

CONCLUSIONS

Based on the results, it was concluded that :

1. Diagnosis of diabetic retinopathy can be done by examining the eye fundus image using fractal dimension analysis of box-counting method and KNN.
2. The value of fractal dimension of the fundus image with a retinopathy diabetic is greater than the fractal dimension of the normal fundus image and the value is increase corresponding with the severity of diabetic retinopathy.
3. Classification of diabetic retinopathy using fractal dimension analysis with box-counting method and image processing obtained the accuracy value 89,17% with 3NN or 4NN. It means that the classification of diabetic retinopathy using fractal dimension analysis had a good performance.

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