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AUTOMATED DETERMINATION OF MACULA CENTRE POINT BASED ON GEOMETRICAL AND PIXEL VALUE APPROACHES TO SUPPORT DETECTION OF FOVEAL AVASCULAR ZONE

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Abstract. *The centre of macula can be used to support the determination of foveal avascular zone which is one of the features in automated diabetic retinopathy detection. The centre of macula detection novel approach is divided into two parts, namely geometrical and pixel value approaches. Geometrical approach is based on the orientation of centre of macula into the optic disc centre point, whereas pixel value approach is performed by finding the centre of several dark pixels on the particular region of interest. Validation of the centre of macula detection method shows that the correlation coefficient obtained between detected FAZ of the proposed method and FAZ of ophthalmologist's is 0.81. Correlation coefficient achieved between detected FAZ of the proposed method and the grade provided by MESSIDOR database is 0.56. Finally, correlation coefficient between detected FAZ of ophthalmologist's and the grade is 0.49. These promising results indicate that the proposed scheme is reliable to be implemented in the development of a computerized system to assist ophthalmologists in monitoring and diagnosing diabetic retinopathy.*

Keywords: Diabetic retinopathy, Foveal avascular zone, Centre of macula, Geometrical approach, Pixel value approach

1. **Introduction.** Blindness affects 60 million people worldwide. The major causes of permanent blindness include retinal related disease such as diabetic retinopathy (DR) and glaucoma. Diabetes occurs when the pancreas organ does not pull out enough insulin or the body is unable to process the insulin secreted by pancreas properly. Meanwhile, around 415 million worldwide people in 2015 lived with diabetes. Every six seconds, a person dies because of diabetes as reported by the International Diabetes Federation (IDF) in 2015 [1-3].

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Diabetes affects heart, kidneys, eyes, nervous system and other organs. Over time, diabetes affects the eyes, including retina, which causes early and permanent vision loss. The complication of diabetes that attacks the retina is commonly associated with diabetic retinopathy [4-6]. DR occurs when diabetes damages blood vessels into the retina located at the rear of the eye. On the retina, especially on the macula, the blood vessel leaks and forms several features such as microaneurysms and exudates [7,8]. The central part of the macula is called as the foveal or foveola, in which foveal avascular zone (FAZ) is located and represents the retinal region of greatest visual acuity.

FAZ is the most accurate vision zone on the retina. According to [9], determination of the FAZ is one of the necessary steps in any study of retinal diseases. Figure 1 shows the properties of retinal images including the optic disc and macula. Optic disc appears as bright area while macula comes with dark region in centre of retinal images. These properties are often used as the feature in detecting those retinal image components. Any pathology or lesion found in the macula, the main part of vision system becomes more dangerous [10,11].

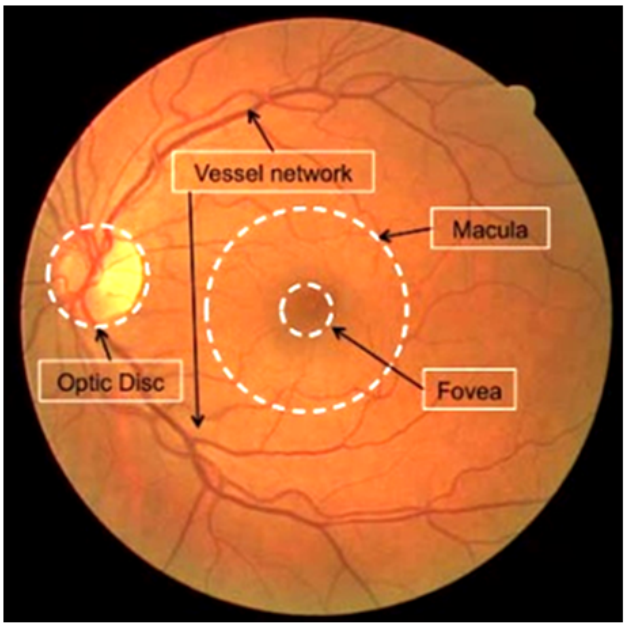

FIGURE 1. Retinal image component

Fundus images are taken by fundus camera and are used to observe and record the optic disc, optic nerve, vitreous, foveal, macula, retina and eye's blood vessels conditions [12]. There are some retinal related diseases and common causes of early visual loss and blindness such as age-related macular degeneration (ARMD), diabetic retinopathy, and glaucoma. Ophthalmologists diagnose these retinal diseases by observing and analysing retinal fundus images [13,14].

Any study related to retina, such as early detection of retinal related diseases in particular glaucoma and diabetic retinopathy is significant to prevent major visual field loss and prolongs the effective years of usable vision [13,15,16]. Analysis of retinal fundus image requires experts or trained personnel. Moreover, this work is tedious and time consuming since the screening should be done periodically and it also highly costs [17].

Some studies have been addressed to overcome the aforementioned problems. Geometric active contour model has been explored to segment the optic disc boundary since traditional segmentation algorithms failed to provide good result. Optic disc boundary

drawn manually by an expert was used as ground truth. Furthermore, the macula was localized based on its distance and position with respect to the optic disc as it remained relatively constant. For evaluating the methods of optic disc and macula detection, among 148 images were used in this research. Their method achieved the level of sensitivity and specificity of 99.32%, and 96.6% respectively; however, accuracy was not measured [18].

The other method of the automated localization of the optic disc and macula in retinal fundus images by merging the prediction of multiple algorithms has been conducted to combine their strength and compensate their weaknesses. The location with the maximum number of detectors' outputs became the initial view. It was used to find the optic disc or centre of macula. The proposed method used a majority voting and weighted linear combination based scheme that counted the number of outputs of the algorithms falling in a specified radius circle. Moreover, this proposed method achieved the best performance in detecting optic disc and fovea closest to the centre chosen by the retinal specialist manually [19].

Other method by Garduno-Alvarado et al. [20] for detecting optic disc and macula in fundus images has been developed. This research was based on polynomial approximation of the background of the images to correct inhomogeneous luminosity. Then, the use of the cross-correlation in the frequency domain between the images and a steerable template was conducted. This method was validated using 38 photographs local database of patients suffered diabetic retinopathy and showed 100% optic disc centres located within the OD area and 90% of macula centre was located within the MC area. Optic disc and macula detection approach by Poshtyar et al. [21] has also been developed using the information of optic disc and macula characteristics, i.e., circular and bright region and a yellow portion of the posterior retina, respectively. This proposed method has some pre-processing steps, such as morphological operation, adaptive thresholding and arithmetic operations. Spatial information of optic cup method was chosen to detect optic disc centre and macula. Optic cup is a centre region in optic disc with the brighter pixel values than optic disc. This approach can identify 58 ODs out of 70 images accurately and efficiently.

The location of the major anatomical structures in colour fundus photographs, such as the optic disc, the macula and the vascular arch was determined automatically in [22]. These structures were found by fitting a single point-distribution-model to the image, which contains some points on each structure. The system was developed and trained on a set of 500 screening images, and was tested on a completely independent set of 500 screening images consisting of 100 pathological images. The validation of this result was divided into two parts. For all images screening set, these approaches were able to find the vascular arch, macula, and optic disc location with accuracy of 93.2%, 94.4%, and 98.4%, respectively.

Based on the aforementioned research works, automated detection of optic disc and macula centre is a popular research topic. However, some of them have their own weaknesses, particularly in terms of automation. Moreover, many algorithms described above used their own database, which commonly consists of the healthy retinal images only. Therefore, in this research, a novel method to automatically detect the centre point of macula in healthy and unhealthy retinal colour images is proposed to assist ophthalmologists in diagnosing retinal related diseases, especially diabetic retinopathy and glaucoma. This manuscript is organized as follows. Section 2 explains the used dataset and the research methodology. The research results are presented in Section 3. Section 4 provides the general discussion, while Section 5 presents the conclusion and suggestions for the next research works.

2. **Materials and Method.** Colour fundus images from publicly available database, namely Messidor [23], are used in the development of automated detection of centre of macula. This database contains 1200 healthy and unhealthy colour retinal images. Nevertheless, only 59 manually selected images are used in this research work, since the other images have poor quality [24]. In the Messidor dataset, there are four grade classes of diabetic retinopathy, i.e., grade 0, grade 1, grade 2 and grade 3.

In the centre of macula detection, overall steps are divided into two stages; those are the detection based on geometrical approach and the detection based on pixel value approach. Detailed steps conducted in this research work are shown in Figure 2.

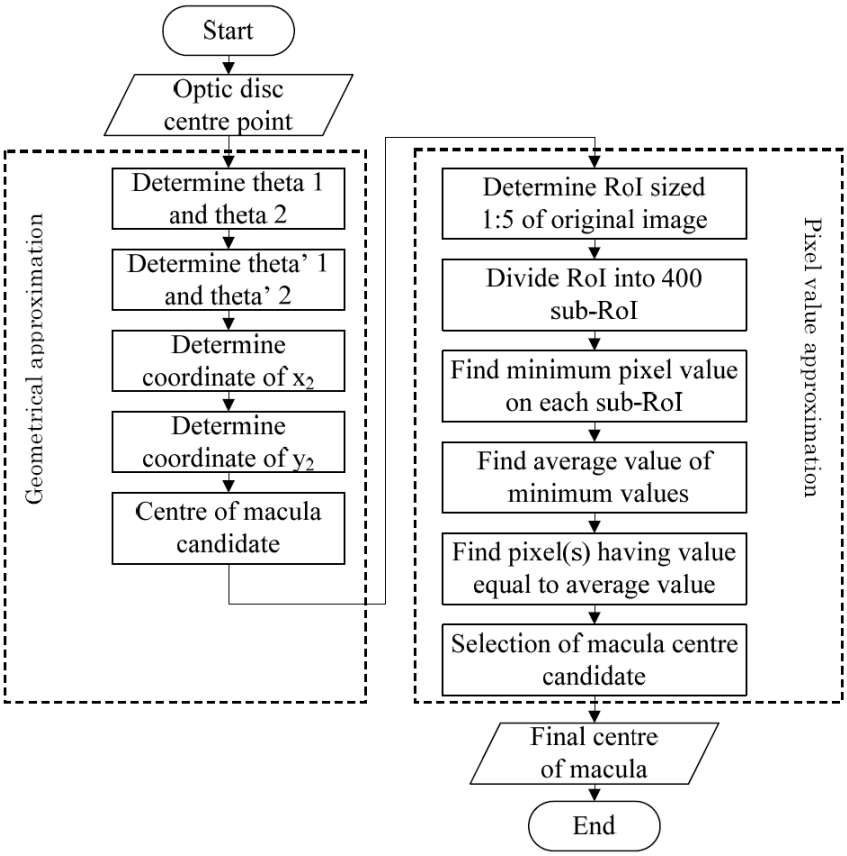

FIGURE 2. Flow chart of the proposed scheme

2.1. **Geometrical approach.** Detection of centre of macula based on geometrical approach works by measuring the orientation of centre of macula into the optic disc centre point. The optic disc centre point candidate is achieved by using developed scheme in [25]. An example of detected optic disc centre point is shown in "+" marker of Figure 3.

Firstly, two imaginary lines are drawn to connect optic disc centre point candidate $(O(x_1, y_1))$ to the farthest top and the bottom corner of image as illustrated in Figure 4. According to the position of the right eye optic disc, it is commonly located on the left side of retinal image; hence, the imaginary lines are connecting the optic disc centre point candidate to the right-top and right-bottom image corner. In contrast, for the left eye, the optic disc is commonly located on the right side of retinal image; therefore, the imaginary lines are connecting optic disc centre point candidate to the left-top and left-bottom image corner. Having denoted the corners by A and B, there will be three lines, i.e., $\overline{OA}$, $\overline{OB}$ and $\overline{AB}$. If there is a new point called C, which is located in the middle of $\overline{AB}$, the new imaginary line $\overline{OC}$ can be drawn to connect O and C. From the triangle of

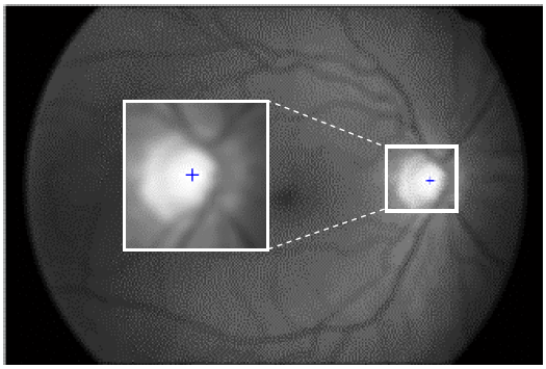

FIGURE 3. Optic disc centre point candidate in retinal images [25]

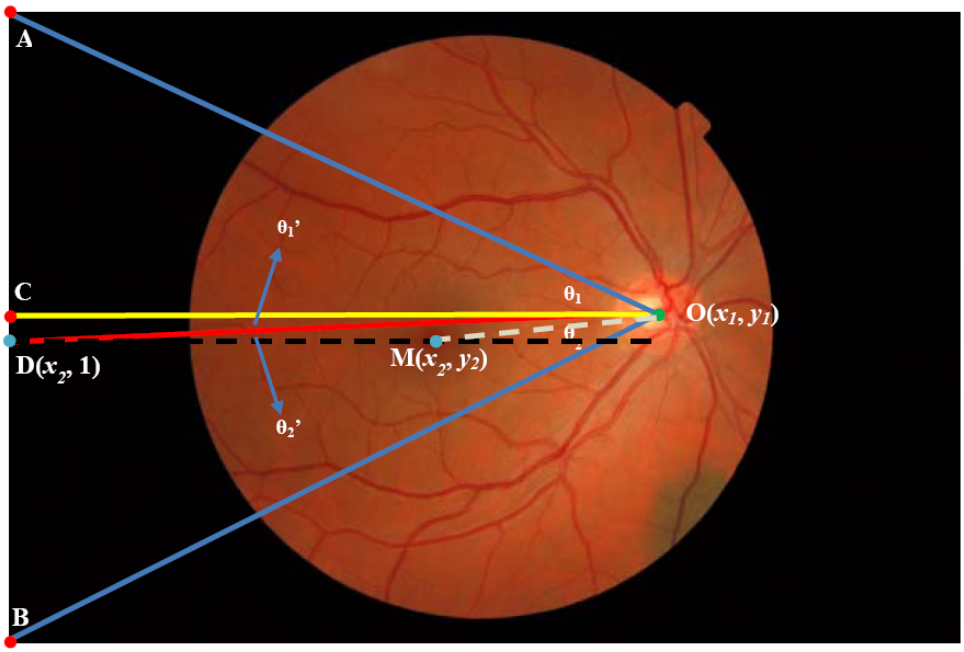

FIGURE 4. The centre of macula detection based on geometrical approach illustration

AOC and BOC, two imaginary angles AOC (θ_1) and BOC (θ_2) can be introduced using Equation (1) and Equation (2).

$$\theta_1 = \tan^{-1} \frac{\overline{AC}}{\overline{OC}} \tag{1}$$

$$\theta_2 = \tan^{-1} \frac{\overline{BC}}{\overline{OC}} \tag{2}$$

Afterwards, by averaging the value of θ_1 and θ_2, θ is calculated. The next process is determination of difference value of θ_1 to θ and θ_2 to θ, which are denoted by θ_1' and θ_2'. The values of θ, θ_1' and θ_2' can be measured from Equation (3) to Equation (5).

$$\theta = \frac{\theta_1 + \theta_2}{2} \tag{3}$$

$$\theta_1' = \theta_1 - \theta \tag{4}$$

$$\theta_2' = \theta_2 - \theta \tag{5}$$

Having obtained the value of θ_1' and θ_2', the candidate of vertical position of the centre of macula (x_2) is determined. From the vertical position of centre of macula candidate

obtained previously, horizontal position of centre of macula candidate (y_2) is determined. The position of x_2 and y_2 is calculated by using Equation (6) and Equation (7). Here L and T are the length and width of original image, respectively.

$$x_2 = \begin{cases} x_1 + (y_1 - 1)\tan\left(\dfrac{T - x_1}{x_1 - 1}\right)\theta_2', \ y_1 > L/2, \ \theta_2 > \theta_1 \\ x_1 + (B(y) - y_1)\tan\left(\dfrac{T - x_1}{x_1 - 1}\right)\theta_2', \ y_1 < L/2, \ \theta_2 > \theta_1 \\ x_1 - (y_1 - 1)\tan\left(\dfrac{x_1 - 1}{T - x_1}\right)\theta_1', \ y_1 > L/2, \ \theta_2 < \theta_1 \\ x_1 - (B(y) - y_1)\tan\left(\dfrac{x_1 - 1}{T - x_1}\right)\theta_1', \ y_1 < L/2, \ \theta_2 < \theta_1 \end{cases} \tag{6}$$

$$y_2 = \begin{cases} y_1 - \dfrac{|x_2 - x_1|}{\tan(2.7\theta_2')}, \ y_1 > L/2, \ \theta_2 > \theta_1 \\ y_1 + \dfrac{|x_2 - x_1|}{\tan(2.7\theta_2')}, \ y_1 < L/2, \ \theta_2 > \theta_1 \\ y_1 - \dfrac{|x_2 - x_1|}{\tan(2.7\theta_1')}, \ y_1 > L/2, \ \theta_2 < \theta_1 \\ y_1 + \dfrac{|x_2 - x_1|}{\tan(2.7\theta_1')}, \ y_1 < L/2, \ \theta_2 < \theta_1 \end{cases} \tag{7}$$

2.2. **Pixel value approach.** In the retinal fundus image, macula is a centre dark region and has lower pixel value than other objects. Pixel value approach works based on low intensity pixel value as a dark region. Thus, pixel value approach becomes one of the alternatives for finding the centre of macula automatically. There are some steps which are constructed in this technique. Initially, a region of interest (RoI) sized 1:5 of the original image is determined with the centre of macula candidate as the centre point. This size is considered since it can cover the entire macula area. Then, the RoI is divided into 400 sub-RoIs sized of $L/100 \times T/100$ each. Afterwards, the intensity values of every pixel on each sub-RoI are evaluated and the minimum value ($f_{\min,i}$) of them is taken. Furthermore, the macula intensity value (f_{mac}) is obtained by taking the average value of a set of minimum values.

The centre position of macula (x, y) is finally determined by looking at the pixel in RoI which has the same value of f_{mac}, then finding their centre position. In case there are no pixel values in RoI with the same value of f_{mac}, the centre of macula candidate (x_2, y_2) becomes the final position of centre of macula. $f_{\min,i}$ and f_{mac} are mathematically expressed by Equation (8) and Equation (9).

$$f_{\min,i} = \min_{n=1}^{N} (f_{n,i}), \quad i = 1, 2, \ldots, 400 \tag{8}$$

$$f_{mac} = \frac{1}{400} \sum_{i=1}^{400} f_i \tag{9}$$

with i, n and N denote the i_{th} RoI, n_{th} pixel in an RoI and the number of pixels in an RoI, respectively.

Based on aforementioned explanation, one of the parts of macula is fovea in which fovea avascular zone (FAZ) is located. FAZ is the most accurate vision zone of the retina. Centre of macula is important in detecting FAZ. Thus, the final centre of macula can be used to detect FAZ area automatically and thus assist in the diabetic retinopathy detection and grading based on the size of FAZ area. To validate the proposed scheme,

FAZ area is developed from previous work [24]. Finally, validation test is conducted by calculating the correlation between polygon area representing the detected FAZ and circular area representing the area determined by the ophthalmologist. Furthermore, the correlation between polygon area and grade, the correlation between circular area and grade are also validated. As stated in [24], this validation method was a suggestion from the expert. The aim of this validation is to compare FAZ area produced using manual centre of macula [24] and automated centre of macula.

3. **Results.** The determination of macular centre point based on geometrical and pixel value approaches has been proposed. Figure 3 shows the results of this step. The masking and detected centre point are depicted in Figure 5(a) and Figure 5(b). Figure 5(c) represents the result of centre of macula detection based on geometrical approach, whereas the candidate of centre of macula obtained using pixel based approach is shown in Figure 5(d). Then, final centre of macula which is depicted in Figure 5(e) can be used to perform automated FAZ area detection. The detection method of FAZ developed in [24] is used to validate our proposed scheme. Validation is conducted by calculating the correlation between polygon area representing detected FAZ and circular area representing the area of ophthalmologist's. Moreover, the correlation between polygon area and grade, the correlation between circular area and grade are also considered. Table 1 represents the FAZ area of the proposed method and ophthalmologists of each image together with their grades.

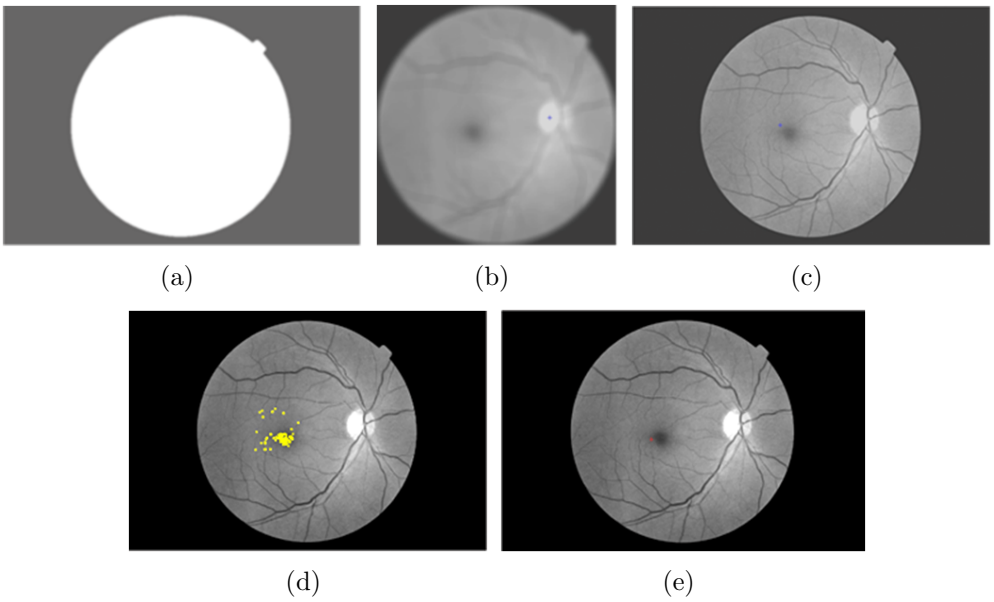

FIGURE 5. Image results of (a) masking image, (b) optic disc centre point, (c) centre of macula based on geometrical approach, (d) centre of macula candidates based on pixel value approach and (e) final centre of macula

4. **Discussion.** Two main steps have been proposed in this study. Those are centre of macula detection based on geometrical approach and centre of macula detection based on pixel value approach.

Using the same method used in previous work [25], optic disc centre point candidate detection is started by green channel extraction as high contrast image. At first, green channel is extracted due to its best contrast compared to other channels. Since the image

TABLE 1. FAZ area of the proposed method and that of the ophthalmologists from each image

Image	Polygon area (pixels)	Circle area (pixels)	Grade	Image	Polygon area (pixels)	Circle area (pixels)	Grade
1	1151	6085.26	0	32	5798.5	16805.16	1 and 2
2	4475	11216.27	0	33	8327.5	16418.75	1 and 2
3	1034.5	1961.92	0	34	7045.5	12199.59	1 and 2
4	3185	15506.90	0	35	3290	12048.79	1 and 2
5	4572	9211.15	0	36	705	2728.47	1 and 2
6	1078	2093.09	0	37	8780.5	20992.91	1 and 2
7	5192	13770.39	0	38	711	4657.41	1 and 2
8	7539.5	38398.12	0	39	6875.5	12790.21	1 and 2
9	7084	15328.62	0	40	7884.5	32764.46	3
10	3567	7068.58	0	41	10082.5	19045.91	3
11	8738	29507.41	0	42	17239	32403.17	3
12	5751	9397.29	0	43	8415	22658.74	3
13	2444.5	10312.28	0	44	15708	35456.81	3
14	2836.5	5674.50	0	45	9658	24263.31	3
15	4516.5	11217.06	0	46	5139	45871.18	3
16	3433	10895.83	0	47	7230.5	13198.62	3
17	3795	9507.24	0	48	16602	44045.91	3
18	3381	9239.42	0	49	25625	61082.77	3
19	5972	19475.52	0	50	3661	6544.72	3
20	4485.5	13723.26	1 and 2	51	10117.5	19855.65	3
21	6654.5	14524.37	1 and 2	52	8420	28930.93	3
22	4656	12079.42	1 and 2	53	12512.5	30368.21	3
23	8262	26722.39	1 and 2	54	14056.5	26760.87	3
24	5533.5	14590.34	1 and 2	55	14250.5	24826.44	3
25	1837.5	7468.35	1 and 2	56	1154	5061.89	3
26	2831.5	7769.94	1 and 2	57	7296	13653.36	3
27	4116	36339.59	1 and 2	58	6301	18438.79	3
28	1056.5	2018.47	1 and 2	59	4121	13440.52	3
29	10570	21042.39	1 and 2	**Circle and polygon area correlation**			**0.81**
30	2348	5582.61	1 and 2	**Polygon area and grade correlation**			**0.56**
31	6234.5	22698.79	1 and 2	**Circle and grade correlation**			**0.49**

in Messidor dataset has a large background, region of interest (RoI) is produced. Before achieving RoI image, masking process is applied by using the masking image in Figure 5(a). The aim of masking process is to get the edge of retinal image boundary so that the RoI image (Figure 5(b)) only consists of boundary of retina as an object. Afterwards, optic disc centre point is obtained using the method described in [25].

In geometrical approach, centre of macula is detected based on its orientation to the optic disc centre point. Equation (1) until Equation (5) are used to measure the rough orientation of centre of macula to the centre of optic disc. Thereafter, Equation (6) and Equation (7) are used to produce the exact horizontal and vertical position of centre of

macula based on geometrical approach, respectively. The example of detected centre of macula by using this approach is shown in Figure 5(c). The result of this method seems to be not desirable, so that we combine this method with the pixel value approach as follows.

The obtained centre of macula based on geometrical approach is used to produce the RoI of macula having size 1:5 of original image size. Then, as described above, the RoI is divided into 400 sub-RoI; each has size of $L/100 \times T/100$. On each sub-RoI, the minimum value ($f_{\min,i}$) of contained pixels is calculated by using Equation (8) followed by determining the macula intensity value (f_{mac}) using Equation (9). Afterwards, some pixels which have the same value of f_{mac} are extracted and denoted as f_{mac} pixels (Figure 5(d)). Eventually, the final centre of macula (x, y) is determined by finding the centre coordinates of f_{mac} pixels. In case there is no pixel value in RoI with the same value of f_{mac}, the centre of macula candidate (x_2, y_2) becomes the final position of centre of macula. The example of final detected centre of macula can be seen in Figure 5(e). The pixel value approach provides better result than geometrical approach does. In other words, by using the pixel value approach, the centre of macula detection performance can be improved.

The final centre of macula can be used to detect FAZ area automatically in order to assist the diabetic retinopathy detection and grading system based on the size of FAZ area. The FAZ can also be used to validate the proposed method by calculating the correlation between polygon area representing detected FAZ and circular area representing area of ophthalmologist's, polygon area and grade, and also circular area and grade [24]. As shown in Table 1, the FAZ area of the proposed scheme of each image together is not significantly different from that of the ophthalmologists. The coefficients obtained for those correlation tests are 0.81, 0.56 and 0.49, respectively. The previous results for similar tests obtained in [24] were 0.91 between circle and manual polygon area, 0.77 between manual polygon area and grade, and 0.62 between circle and grade, respectively. These results indicate that the proposed scheme is reliable enough to be used in developing computerized diabetic retinopathy diagnosis system.

5. **Conclusions.** The detection of macula centre point based on geometrical and pixel value approaches has been presented. For automated centre of macula detection, validation has been conducted by measuring the correlation between polygon area (representing detected FAZ) and circular area (representing area of ophthalmologist's), between polygon area and grade, and between circular area and grade. The coefficients obtained for those correlation tests are 0.81, 0.56, and 0.49, respectively. The promising results indicate that the proposed method has a potential to be implemented in the development of a computerized retinal related disease diagnosis system. For further research work, it is suggested to develop better technique to perform automated centre of macula recognition and automated detection of diabetic retinopathy and glaucoma diseases.

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