Towards Early Detection of Diabetic Retinopathy Using Extended Fuzzy Logic

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***Abstract*—Diabetic Retinopathy (DR) is a common cause for blindness and severe vision loss in diabetic patients. Early detection of DR is very crucial to enable timely treatment that may help in maintaining sufficient vision quality. The aim of this work is to present a new automated method for early detection of DR and calculating the percentage of the damaged caused by DR in the retina. The calculation of the percentage is done using Extended Fuzzy Logic (FLe) with Ordered Weighed Averaging (OWA) as an aggregation method. The proposed model is designed to be used in these areas, when human experts are not easily found or the cost of detecting the DR is excessively high, also when diabetic patients need to know about their retina state approximately.**

***Index Terms*—Diabetic Retinopathy (DR), Extended Fuzzy Logic (FLe), microaneurysms, exudates, hemorrhages, Ordered Weighted Averaging (OWA)**

I. Introduction

Diabetic Retinopathy (DR) is considered a leading cause to blindness in working-age adult [1]. It refers to the changes that occur to the retina over a period of time in diabetes and these changes happen as a result of changes in the blood vessels that feed the retina and could cause vision problems [2]. In 2009, DR was nominated to be the fourth most frequently chronic disease worldwide, and by the year of 2030, it is estimated to reach the level of being the second most frequent disease [3]. Early detection of DR is very crucial to enable timely treatment that will help maintaining sufficient vision quality [3], [4].

A major investment has to be made in screening program, to accomplish the goal of early detection of DR. By The screening for the development of DR in diabetic patients, the risk of being blind may reduce to 50% in these patients. The screening programs use coloured fundus images that are viewed by ophthalmologist in order to determine the severity of the disease. The main disadvantage of these systems is the need for ophthalmologist to grade the image [2], [3].

There are many risk factors associated with increased potential of DR which includes: Duration of diabetes, poor control of diabetes, High blood pressure and High cholesterol level. Regarding the diabetes duration as the duration become longer the patient have greater possibility of developing DR and this risk factor considered the strongest factor for determining the DR prevalence. The poor control of diabetes also increases the development of DR, the control level can be known by getting the value of Hemoglobin A1C test [5]. This test is a blood test. It used for diabetes management because it provides information about a person's average levels of blood sugar for the past 3 months [6]. As the level of HbA1c gets lower it will assist in reducing the development and progression of DR. For DR patients, the HbA1c target level should be 7.0% or less. Regarding the blood pressure, as it gets lower, it will assist in reducing the development of DR. For DR patients, the blood pressure target should be lower than 130 mmHg. For the cholesterol level, normalizing the blood lipid levels also help in reducing the cardiovascular risk and also DR [5].

Diabetic retinopathy could be classified into two types: Non-Proliferative Diabetic Retinopathy (NPDR) and Proliferative Diabetic Retinopathy (PDR). The NPDR type is considered the first stage in diabetic retinopathy and it could be further classified into 3 stages mild, moderate and severe. The mild NPDR earliest sign of diabetic retinopathy is Micro-aneurysms which are small, red dots in the superficial layers of the retina and are caused by weakening of blood vessels in which they start to break, resulting in leakage of blood around them. As Micro-aneurysms spread into retina's deeper layers, another sign appears similar to them called hemorrhages which considered the moderate stage of NPDR [2]. As DR progresses, Exudates may appear which considered the sever level of NPDR and it leads to form lipids. These lipids are leaking from weakened blood vessels [7]. Fig. 1 represents all NPDR's signs along with retinal landmarks.

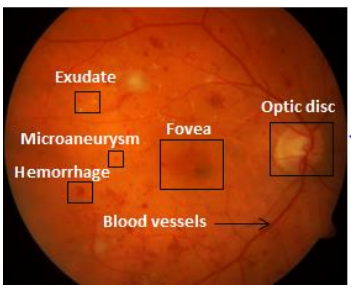

Figure 1. NPDR signs

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The PDR stage is the second stage in DR. in this stage a new blood vessels start growing abnormally with fibrous proliferation as a result of retinal ischaemia [5]. In this paper focus on the NPDR stage, that is the early stage of DR.

The aim of this work is to present a new automated way to early detect and calculate the damage caused by DR in retina. Extended fuzzy logic (FLe) and Order Weighted Averaging (OWA) operator will be taken together as double folded milestone in revealing the uncertainty in detecting the DR.

This paper is organized as follows. Section II talks about previous related work, Section III discussed the methodology used, Section IV discussed the proposed model in details; finally Section V gives a brief conclusion about this paper.

II. Related Work

A lot of researchers have achieved many good results in Identification and Classification of early detection of DR through soft computing techniques. In [8], Jones, Kumar and Purushothaman discussed the usage of fuzzy logic and back propagation neural network to identify the presence of exudates in fundus image. In [2], Habashy discussed the use of Fuzzy C-Means clustering algorithm to detect deferent DR features such as the structure of blood vessels, microaneurysms, and exudates and identify the DR stage. In [9], Ram, Joshi and Sivaswamy present a new method for automatic microaneurysms detection from fundus image by designing a model that discards specific classes of clutter while allowing majority of true microaneurysms to pass. The remaining microaneurysms after the last rejection stage are assigned a score based on their similarity to true microaneurysms. In [10], Antal and Hajdu present a method that combines several preprocessing and candidate extractors before starting the classification phase. They used a modular model and a simulated annealing-based search algorithm in order to find the best combination. In [11], Júnior and Welfer proposed a new method that detects microaneurysms and hemorrhages. This method is based on mathematical morphology and in removing components of retinal anatomy to detect the lesions. In [12], Quellec et al. proposed a new method based on template matching using an optimal wavelet transform. This matching is done by using a generalized Gaussian template in wavelet domain. In [13], Kamil proposed a new technique that uses the traditional operators in combination with fuzzy logic based on fuzzy inference system. This technique is use for edge detection. The results show that the proposed technique is better than of traditional techniques.

However, in other area there are some studies that discuss the usage of FLe. In [14], Aliev, Alizadeh and Guirimov addressed the decision making with unprecisiated information based on FLe and fuzzy geometry. In [15], Tolosa and Guadarrama used the concept of spray pen in FLe as a combination of points that imply the perception of a non-expert users and their confidence degree. They used this interpretation to develop a tool that obtains an appropriate approximation for fuzzy sets by three algorithms that represents different disciplines: Naïve-Greedy, Alternative Greedy, and Iterative.

Some studies demonstrate the usage of FLe with OWA to enhance the result f-validity. In [16], Imran and Beg introduced a kind of fuzzy geometry based on FLe with OWA, in which the description of the geometric shapes is done by an exponential function in regard to their prototypes in classical geometry. In [17], Rahman and Beg discussed the usage of FLe and OWA in estimation of f-validity of geometrical object.

Our work is aimed to introduce an automated method that detect DR using FLe and OWA .To the best of our knowledge we have not found any such work has been done before.

III. Methodology

A. Extended Fuzzy Logic

To develop a clear understanding of extended fuzzy logic (FLe), it is useful to begin explaining the following two definitions:

- Fuzzy logic

Fuzzy Logic was introduced by Lotfi A. Zadeh in 1965. Fuzzy Logic (FL) is a many-valued logic, which allows intermediate values to be defined as real numbers between 0 and 1. It also can be defined as a precise logic of imprecise reasoning in which the membership functions and generalized constraints are specified [18].

- Unprecisiated fuzzy logic

FLu was also introduced by Lotfi A. Zadeh and in contrast to FL, it is an imprecise logic of imprecise reasoning in which membership functions and generalized constraints are not specified [18].

FLe is a result of combining both FL and FLu. It adds to fuzzy logic the ability to deal with imperfect information imprecisely which is FLe main advantage. So, it can be defined as a conceptual system of reasoning in which the objects of discourse allowed to be associated with imperfect information [18]. Since FLe is a result from lowering of standards of precision in fuzzy logic, it can be used when the p-valid reasoning is infeasible, carries an excessively high cost or is unneeded [18]. An important term that should be introduced when discussing FLe is f-validity.

- The concept of f-validity

f-validity provides a measure of degree of blondness of any f-object to the exact object [17]. In other term f-validity is the possibility (fuzzy degree) of the validity. In FLe, we can generate many solutions, and then decide which one is to be selected based on a validity measure [19]. The computation of f-validity is performed by generating the membership values followed by applying the f-theorem.

- The concept of f-theorem

f-theorem stands for fuzzy-theorem which is the fuzzification of the exact theorem and it has the ability to deal with imprecise information. In f-theorem, the f-concepts are formalized in terms of membership function [17].

$$\mu\ (f\ \text{-theorem}) = \mu_1 * \mu_2 * \mu_3 * \ldots\ldots\ \mu_n \quad (1)$$

where μ is the membership function, the above f-theorem fails in some situations, for example considering having 3 membership functions have the values 0.1, 0, 0.5 respectively will result in having an f-validity = (0.1) *(0) * (0.5) =0

Because of the problem of pure And-ness the OWA will be used to aggregate the membership function.

B. Ordered Weighted Averaging (OWA) Operator

Ordered Weighted Averaging (OWA) operators were introduced by Yager in 1988 [20]. This operator is used when the decision is somewhere between AND-ness and OR-ness. The OWA operation includes three steps:

1) Reorder the input parameters in descending order

In this step the input parameters are rearranged in decreasing order in which that $a_{\sigma(i)}$ is the largest value in the set (a_1, a_2..., a_n) such that $a_{\sigma(i)} \geqslant a_{\sigma(i-1)}$. However, the weights of an operator R is not associated to any value of the input parameters, instead it is associated with position of the input parameter.

2) Determine weights for these parameters

The weights could be determined using the mathematical representation of relative quantifier which can be defined as follows:

$$Q(r) = \begin{cases} 0 & if\ r < a \\ \frac{r-a}{b-a} & if\ \ a \leq r \leq b \\ 1 & if\ r > b \end{cases} \quad (2)$$

where a, b, r ∈ [0, 1]

The calculation of the wi from the Quantifier Q with n number of criteria is done as follows

$$W_i = Q\left(\frac{i}{n}\right) - Q\frac{(i-1)}{n} \quad (3)$$

where $i = 1, 2, \ldots, n$ and $Q(0) = 0$

3) OWA operator aggregate these ordered parameters

An OWA operator determines the f-validity by aggregating the input parameters and the weights as shown below:

$$f(a_1, a_2, \ldots, a_n) = \sum_{i=1}^{n} w_i a_{\sigma(i)} \quad (4)$$

IV. Proposed Model

In our proposed model, we present a new automated method to detect and calculate the percentage of DR's impact on the retina which can be used in any area when human experts are not easily found or the cost of detecting the DR is excessively high, also when diabetic patients need to know about their retina state approximately. In this work a set of information will be taken from the patient that includes: information regarding the DR's risk factors and retina fundus image. Then the f-validity value will be computed using this information after generating the membership functions and applying the f-theorem. if f-validity approaches to 1 this indicates that this person's eye is normal and it's not infected by DR. but as f-validity approaches to 0 this indicates that that the diabetic patient is more likely to have diabetic retinopathy with high level of severity. this proposed method includes 3 steps which are : getting the medical information of the diabetic patient, getting the retina fundus image of the diabetic patient and apply the image processing techniques to detect the DR's early sign's and find the difference between the patient retina fundus image compared to normal eye and the last step is generating the membership functions using the exponential function and use the f-theorem along with OWA operator to find the f-validity value which indicates how patient information relate to normal person information.

1) Getting the patient medical information

Here patient's medical information is considered as the DR risk factors associated with DR development, knowing these information considered essential in determining the severity of DR. as discussed in Section 1 these risk factors includes: Duration of diabetes, poor control of diabetes, High blood pressure and High cholesterol level. The value of these risk factors will be compared with values of normal person with no diabetes to find the difference which will be used later in step 3. Table I illustrates the normal people values in terms of risk factors.

TABLE I. Risk Factors Table

Risk factors	Normal value
duration of diabetes	N/A
blood sugar level (A1c test) [21]	below 5.7 %
blood pressure [22]	Less than 120/80 mm Hg
cholesterol level [23]	Less than 200 mg/dl

2) Detecting DR's early signs

As discussed in the introduction, the early signs of NPDR includes: Micro-aneurysms, Hemorrhages and Exudates. The detection of these signs requires some steps which are Preprocessing, Localization and segmentation of the optic disk, Segmentation of the retinal blood vessels and Localization of fovea then Localization and segmentation of DR's sign starts. These processing steps will be applied first on the retina fundus image which belongs to normal person who don not suffer from diabetes. Second, it will be applied on the test input fundus image. Finally, earth mover's distance algorithm will be used to find the difference between the histograms of the two processed images which will be used later in step 3. For each of the following process the algorithms that would be used is illustrated in Table II.

TABLE II. Process Algorithms

Process	Algorithm
Preprocessing	Histogram localization , contrast limited adaptive histogram
Segmentation	Morphological segmentation
Comparison	Earth Mover's Distance

3) Compute f-validity value

After getting the difference between the normal person and diabetic patient in terms of fundus image and the risk factors, the membership function would be generated using the exponential function.

The membership function is defined as follows

$$\mu = e^{-|d|} \quad (5)$$

where d is the difference.

As d increases the membership function approaches to 0, Moreover, if d decreases the membership function approaches to 1 (Fig. 2).

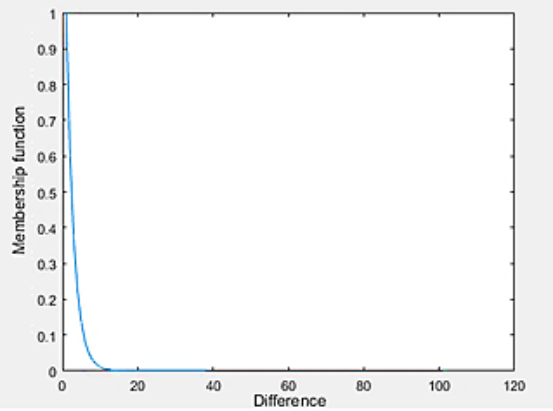

Figure 2. Plot of the membership function

For instance, considering the blood pressure of the diabetic patient is 120/80 so the difference between the normal pressure and the patent's pressure is d = 0 which results in μ= 1. Another example is taken when the blood sugar level is 7% which results that d = 1.3 and μ=0. 27.

After generating all the membership functions for all the risk factors and the fundus image f-theorem along with OWA operator would be used to generate the f-validity which results in the following formula:

$$\mu(f - valditiy) = \sum_{i=0}^{n} w_i \, \mu_{di} \quad (6)$$

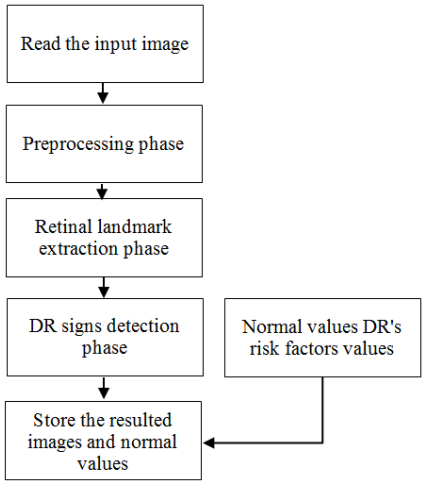

Figure 3. Training process

In Fig. 3-Fig. 4, an illustration of the proposed model block diagram is shown. In Fig. 3, the system will take the healthy retinal fundus image along with the values of DR's risk factors, perform pre- processing techniques and save the resulted image. Moreover in Fig. 4, the system will take the tested fundus image with the patient DR's risk factors, perform the same pre- processing techniques and find the difference between the trained and the tested images.

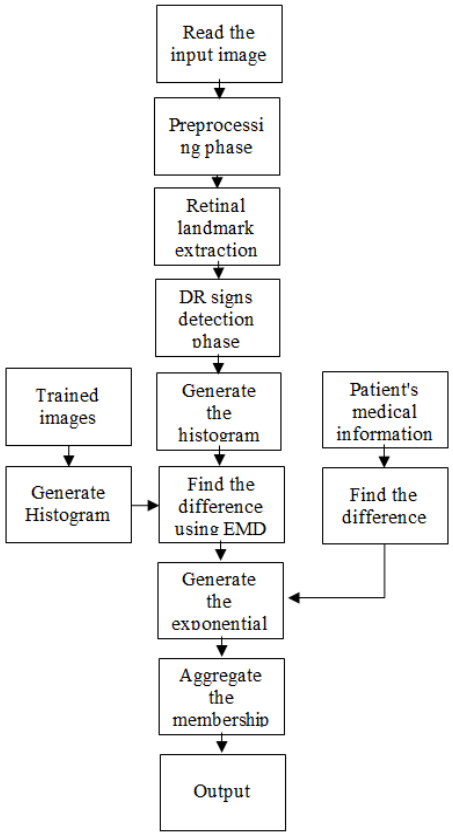

Figure 4. Testing process

V. Conclusion

This paper has given an overview about DR and its prevalence. Furthermore, it has presented a new automated method to detect DR and calculate its impact on the retina as a fuzzy value. The proposed method takes into account the DR's risks factors and the signs of DR in retina fundus image. For the future work, a system will be developed using that proposed method.

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