Automatic Detection of Hard Exudates in Diabetic Retinopathy Using Morphological Segmentation and Fuzzy Logic

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Summary
Retinal image analysis is an essential step in the diagnosis of various eye diseases. Diabetic Retinopathy (DR) is globally the primary cause of visual impairment and blindness in diabetic patients. Early diagnosis through regular screening and timely treatment has proven beneficial in preventing visual impairment and blindness. In this paper we have proposed a novel approach to automatically detect diabetic retinopathy from digital fundus images. The digital fundus images are segmented employing morphological operations to identify the regions showing signs of diabetic retinopathy such as hard exudates, soft exudates and the red lesions: microaneurysm and haemorrhages. Various color space values of the segmented regions are calculated. A fuzzy set is formed with the color space values and fuzzy rules are derived based on fuzzy logic reasoning for the detection of diabetic retinopathy. Experimental evaluation on the publicly available dataset DIARETDB0 demonstrates the improved performance of the proposed approach in the diagnosis of diabetic retinopathy.

Keywords:
Ophthalmology, Diabetic Retinopathy (DR), Digital Fundus Images, Segmentation, Morphological Operations, Color Space, Fuzzy Logic, Standard Diabetic Retinopathy Database (DIARETDB0).

1. Introduction

A fundamental and vital analytic procedure in ophthalmology for detecting eye diseases involving structural and functional transformations in the vasculature is the analysis and interpretation of the retinal images called fundus images. Certain instrumental features such as optic disk, exudates, the structure and widths of vessels, etc., are extracted and analyzed to aid the ophthalmologists. The vital manifestations of diabetic retinopathy and retinopathy of prematurity and cardiovascular risk are the changes in retinal vasculature, such as haemorrhages, angiogenesis, increase in vessel tortuosity, blockages and arteriolar-venular diameter ratios [2]. Diabetic retinopathy (DR) often remains undetected until acute vision loss occurs, making it the primary cause of blindness globally, even though it has comparatively less incidence than the other causes [3]. Diabetic Retinopathy has been proved to agonize 17% and 97% of the subjects after 5 and 15 years of the diagnosis of diabetes respectively [4].

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Alterations in blood vessel diameter, microaneurysms, lipid and protein deposits also known as hard exudates and cotton wool spots depending on the features, haemorrhages and new vessel growth are all characteristics of Diabetic Retinopathy [5, 6]. The impairment of vision and blindness can be prohibited if detected prematurely through regular screening and treated accordingly. Diabetic retinopathy can occasionally be suppressed either with the aid of laser or through surgical therapies once diagnosed in the early phases. The threat of vision impairment and blindness can considerably be decreased by these treatments since they lessen the advancement of diabetic retinopathy. Once damaged by DR the effects are permanent and so early treatment is considered vital [7]. Thus premature diagnosis and treatment of Diabetic Retinopathy is essential to avoid visual impairment and blindness in diabetic patients [9]. Automated Diabetic Retinopathy screening is facilitated by combining direct digital images acquired using fundus cameras alongside powerful image processing and analysis techniques [3].

Ever since the conference on diabetic retinopathy held in Liverpool UK in 2005 recommended digital image processing techniques as one of the methods for the screening of diabetic retinopathy, the usage of the same has been on a steady rise [8]. Commonly, the number of fundus images employed in a diabetic retinopathy screening program, can be forbiddingly huge [9]. Manual analysis is usually averted due to the huge volumes of images involved and so automated image analysis techniques utilized highly. Lately, attention towards the automatic segmentation of color retinal images has increased with regard to its vital role in the registration of images and diagnosis of diseases such as diabetic retinopathy and hypertension.

Machine learning computer systems can accurately diagnose the red lesions and retinal vasculature from the retinal color images as described by various authors [9], [10], [11] [12]. Artificial Neural Networks have been proved beneficial in the automatic detection of diabetic retinopathy as proposed by G.G. Gardner et al. [13]. C. Sinthanayothin et al. [14] used the Region Growing Segmentation (RRGS) algorithm on a 10x10 window to

achieve automated detection of diabetic retinopathy from digital fundus images. Color features on Bayesian statistical classifiers were used to categorize each pixel into lesions or non- lesions by Wang et al. [15]. The exudates were diagnosed with the aid of grey level variation and morphological construction techniques by Walter et al. [16]. Xiaohui Zhang and Chutatape Opas [17] apportioned the candidate bright lesion areas employing Improved FCM (IFCM). Further the bright lesion frontiers are classified employing a hierarchical Support Vector Machines (SVM) classification structure. Fuzzy C-Means and Morphological based segmentation for diagnosing the exudates from low-contrast images of non-dilated pupils was proposed by Akara Sopharak et al. [18]. The techniques proposed so far, utilized either one or two of the features of diabetic retinopathy to detect its presence in digital retinal images.

In this paper we have presented a novel approach to automatically detect the presence of Diabetic Retinopathy in color digital retinal images. The proposed approach utilizes the morphological operations for the segmentation and fuzzy logic for the identification of features of diabetic retinopathy in digital fundus images. This approach utilizes the features like hard exudates, soft exudates and the red lesions such as Microaneurysm, haemorrhages of diabetic retinopathy to detect the presence of it in retinal images. The digital retinal images are segmented using the morphological operations to identify the regions showing signs of diabetic retinopathy. The XYZ, YIQ, LUV, HSV and Lab color space of the identified regions are determined and a fuzzy set is formed from the values. Then fuzzy rules are derived from the fuzzy set based on fuzzy logic. These fuzzy rules are used to detect the presence of diabetic retinopathy in digital fundus images. We have used the publicly available dataset DIARETDB0 (Standard Diabetic Retinopathy dataset) for the evaluation of the proposed algorithm.

The paper is organized as follows. Section 2 introduces the concepts and techniques utilized in the proposed work. .Section 3 discusses the segmentation of retinal images using morphological operations. The identification of diabetic retinopathy using fuzzy logic is detailed in Section 4. Conclusions are summed up in Section 5.

2. Prerequisites

The concepts and techniques employed in the proposed work are discussed briefly in this section.

2.1 Diabetic Retinopathy

In an aggravated state of diabetes, abnormalities in the retina are caused leading to blindness and visual impairment in the worst case, the phenomenon being termed Diabetic Retinopathy. The number and austerity of the abnormality ascends over time even though the onset of the disease is not characterized by any significant symptoms. Initially, diabetic retinopathy causes trivial changes in the retinal capillary. Figure 1 exposes the deformities that are diagnosable in the retina as a result of DR and they are subsequently described,

- **Microaneurysms:** The primary abnormality that occurs in the eye due to DR is the Microaneurysm. These are identified as tiny, dark red spots or miniscule haemorrhages, either appearing alone or in clusters, inherent to the light sensitive retina. The Microaneurysm is circular in shape and the size varies from 10-100 microns i.e. 1/12th the diameter of an average optics disc [19]. The disease is not alarming at this phase.
- **Haemorrhages:** These are also termed 'blot' haemorrhages, with regard to their round shape. These are found in the deeper layers of the retina.
- **Hard exudates:** The hard exudates are found in diverse sizes from puny blots to booming tracts with clear peripheries and these are the vital symptoms of Diabetic Retinopathy. Commonly the eye encompasses a fluid that is rich in fat and protein alongside blood, which oozes out from the exudates. Such a phenomenon prevents light from reaching the retina thereby leading to visual impairment.
- **Soft exudates**: In extreme stages of Diabetic Retinopathy, certain spots called the 'cotton wool spots' are identified. The retinal pre capillary arterioles supplying blood to the nerve fiber layer are clogged and associatively the local nerve fiber axons get swollen; thereby creating a cotton wool spot.

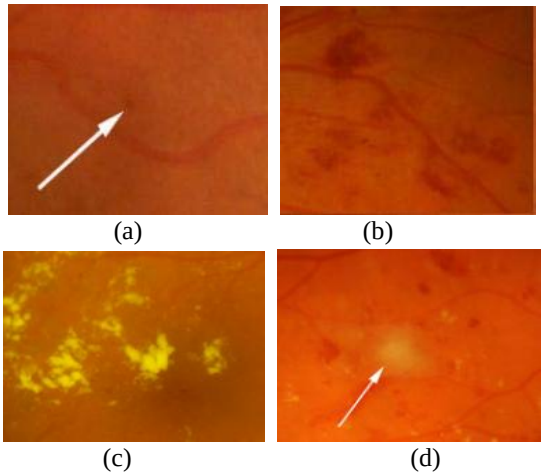


Fig. 1. Abnormalities in the Digital Fundus Images (a) Microaneurysms (marked with an arrow) (b) Haemorrhages (c) Hard exudates (d) Soft exudates (marked with an arrow)

2.2 Mathematical Morphology

One of the most rewarding areas of Image processing is Mathematical Morphology. Set theory forms the substratum of Mathematical Morphology. The objects in an image are analogous to the sets in Mathematical Morphology. The geometric relations amidst the points of such sets serve as the crux for the morphological operations [20]. Some of the premier operations that are instrumental for diverse image processing problems include erosion, dilation, opening and closing.

2.3 Fuzzy Logic

Zadeh introduced the theory of fuzzy logic in the late 1960s [22]. Formerly Lukasiewicz had created the multivalued logic and the fuzzy logic is considered a rediscovery of that approach. Since various real world scenarios could not be represented by two values the fuzzy set approach was introduced. Fuzzy sets, fuzzy membership functions, and fuzzy rules form the elemental components of the fuzzy logic decision making systems. A membership function forms an analogous part of a fuzzy set.

3. Morphological Segmentation

This section details the segmentation of digital fundus images for identifying the abnormalities caused by diabetic retinopathy. The proposed approach utilizes mathematical morphology operations for the segmentation. Initially, the color digital fundus images are converted to gray scale images. Then morphological operations are applied on the grayscale images to segment the abnormal regions. Erosion and dilation are the two elementary operations in Mathematical Morphology. An aggregation of these two represents the rest of the operations [21]. The symbols $\oplus$, Θ, $\circ$, and $\bullet$, respectively denote the four fundamental binary morphological operations: dilation, erosion, opening, and closing. A function $f(x, y)$ denotes the image, where $(x, y) \in R^2$ or Z^2, or simply f , and the function $h(x, y)$, or h will act as the structuring element. The four operations are defined as follows:

Dilation:

$$(f \oplus h)\ (x, y) = \sup_{(r,a)\in H} \{x - r, y - s) + h(r, s)\}$$

Erosion:

$$(f \Theta h)\ (x, y) = \inf_{(r,a)\in H} \{f(x + r, y + s) - h(r, s)\}$$

Opening: $f \circ h = (f \Theta h) \oplus h$

Closing: $f \bullet h = (f \oplus h) \Theta h$

Where sup {} and inf {} denote the supremum and infirmum operation, respectively, and $H \subseteq R^2$ or Z^2 is the support of $h(x, y)$.

In our approach, we have used binary open morphological operation for the segmentation of fundus images. Erosion and Dilation are merged to form a powerful operator called Opening. Commonly this operator gentles the frontiers of an image, breaches narrow Isthmuses and annihilates thin Protrusions. Opening operation is obtained by doing Dilation on Eroded Image. Generally, objects that are adjacent are spaced, objects that are adjoined are detached and the holes within the objects are enlarged by Opening. The grey-scale digital fundus images are segmented using binary open morphological operation. The segmented regions are marked on the color fundus images for further process

4. Detection of Diabetic Retinopathy Using Fuzzy Logic

This section details the detection process using fuzzy logic. The abnormal regions caused by diabetic retinopathy in fundus images are identified by the segmentation process. The different color space values of these regions are calculated using color space conversion equations. A fuzzy set is formed from these color space values. Eventually fuzzy rules are derived from the fuzzy set. These fuzzy rules are used to identify the presence of diabetic retinopathy in digital fundus images. The color spaces we have used in our approach and their conversion equations are as follows.

4.1 Color Space

The aim of color spaces is to aid the process of describing color, either between people or between machines or programs. The color spaces used in our approach are as follows.

4.1.1 XYZ Color Space

The basis of all colorimetry is the *CIE XYZ* (1931) system. The system is defined such that only positive values can be employed to denote all the visible colors and, the Value of Y is luminance. Therefore, the colors of the XYZ primaries themselves are invisible. The matrix transform utilized in transformation from RGB to XYZ is

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412435 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

4.1.2 YIQ Color Space

The YIQ color space is derived from the YUV color space and is optionally used by the $NTSC$ composite color video standard. (Wherein "I" denotes "inphase" and the "Q" denotes "quadrature," which is the modulation procedure that transmits color information.) The matrix transform utilized for the transformation from RGB to YIQ is

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

4.1.3 LUV Color Space

Yet another effort to linearize the perceptibility of color variations is $CIE\ \mathrm{L*u*u*1976}\ \ (CIELUV)$ and it is based directly on $CIE\ \ XYZ$. Even though it is a non-linear color space all the transformations are reversible. The color of the white point of system, subscript n, (D65 in most TV systems) serves as the centre for coloring information. The non-linear relations for L^*, u^*, and v^* are as follows:

$$L^* = 116*(Y/Y_n)1/3 - 16$$
$$u^* = 13L^{**}(u' - u_n')$$
$$v^* = 13L^{**}(v' - v_n')$$

The reference white or the light source are denoted by the values u_n' and v_n'; for the 2° observer and illuminant C, $u_n' = 0.2009$, $v_n' = 0.4610$ [1]. Equations to determine u' and v' are as follows:

$$u' = 4X/(X + 15Y + 3Z) = 4x/(-2x + 12y + 3)$$
$$v' = 9Y/(X + 15Y + 3Z) = 9y/(-2x + 12y + 3)$$

The transformation from (u', v') to (x, y) be:

$$x = 27u'/(18u' - 48v' + 36)$$
$$y = 12v'/(18u' - 48v' + 36)$$

4.1.4 HSV Colorspace

A. R. Smith constructed the Hue/Saturation/Value model in 1978. Instinctive color characteristics such as tint, shade and tone (or family, purity and intensity) form the basis of this model. The colors are defined within a hexcone, with the coordinate system being cylindrical. The value of hue H varies from 0 to 360º. The process for the transformation from RGB to HSV can be briefed as follows. Let $r, g, b \in [0,1]$ be the red, green, and blue coordinates, respectively, of a color in RGB space. Let the greatest of r, g and b, be denoted by $\max$ and the least by $\min$.

$$h = \begin{cases} 0 & if\ \max = \min \\ \left(60^\circ \times \dfrac{g-b}{\max - \min} + 0^\circ\right) \bmod 360^\circ, & if\ \max = r \\ 60^\circ \times \dfrac{b-r}{\max - \min} + 120^\circ, & if\ \max = g \\ 60^\circ \times \dfrac{r-g}{\max - \min} + 240^\circ, & if\ \max = b \end{cases}$$

$$s = \begin{cases} 0, & \text{if } \max = 0 \\ \dfrac{\max - \min}{\max} = 1 - \dfrac{\min}{\max}, & \text{otherwise} \end{cases}, \quad v = \max$$

4.1.5 Lab Color Space

The most beneficial and widely utilized color model is the L^*a^*b color space. In 1976 the CIE refined the XYZ color model, thereby developing a new one, the L^*a^*b color space. Alike XYZ, L^*a^*b describes every color as three components and is device independent as well. Here the luminance is denoted by the value of L and it varies uniformly from 0 for black to 100 for white. The a and b values are expressed such that $+a/-a$ denotes red/green and $+b/-b$ denotes blue/yellow. The non-linear relations for L^*, a^*, and b^* are as follows:

$$L^* = 116*(Y/Y_n)1/3 - 16 \quad for\ Y/Y_n > 0.008856$$
$$L^* = 903.3*Y/Y_n \quad otherwise$$
$$a^* = 500*(f(X/X_n) - f(Y - Y_n))$$
$$b^* = 200*(f(Y/Y_n) - f(Z - Z_n))$$

Where $f(t) = t1/3 \quad for \quad t > 0.008856$

$$f(t) = 7.787*t + 16/116 \quad \text{otherwise}$$

Here X_n , Y_n and Z_n are the tristimulus values of the reference white.

4.2 Fuzzy Sets and Fuzzy Rule Formation Using Fuzzy Logic

Fuzzy sets, fuzzy membership functions, and fuzzy rules form the majority of the fundamental elements of a fuzzy logic system. A fuzzy set is has no defined boundaries. There is a regular and even transition from “belonging to a set” to “not belonging to a set” and this is defined by membership functions. Fuzzy sets are employed to model general linguistic expressions such as ”the object is dark” or ”the object is round” and these functions provide flexibility required by the fuzzy sets in such modeling [23].

A fuzzy set is defined as follows: If S is a collection of objects, then a fuzzy set FS in S is defined as a set of ordered pairs:

$$FS = \{(s, mf(s)) | s \in S\}$$

Where, $mf(s)$ is the membership function of s in S . The value of the membership function ranges from 0 to 1 and can be considered a degree of truth. Fuzzy rules are derived from these fuzzy sets. A fuzzy rule base can contain much number of fuzzy rules. The structure of a fuzzy rule is the following:

$$IF \ \text{Pr}emise \ THEN \ Conclusion$$

Where the premise consists of antecedents linked by fuzzy operator AND.

In this paper, the various color space values serve as the Universe of discourse for the fuzzy logic. The fuzzy set $DR(x, x, x)$ is formed of ordered pairs of various color elements and their corresponding degree of membership. The membership function is defined on the basis of the color values. Five such fuzzy sets are formed with the values corresponding to five different color spaces.

The fuzzy sets for the diagnosis of diabetic retinopathy using various color spaces are defined subsequently.

The fuzzy set wherein XYZ color space is employed for determining the degree of membership is defined as follows:

$$\begin{aligned}
&FuzzyXYZ(x_1, x_2, x_3) = \\
&\{0, if color(x_1, x_2, x_3) < (1,2,0) \,\&\&\, if \ color(x_1, x_2, x_3) > (106,121,48), \\
&1, if \ (50,55,12) <= color(x_1, x_2, x_3) <= (60,66,16), \\
&((abs(1 - x_1) + abs(2 - x_2) + abs(0 - x_3))/3)/100, if \ (1,2,0) <= color(x_1, x_2, x_3) < (50,55,12), \\
&(((106 - x_1) + (121 - x_2) + (48 - x_3))/3)/100, if \ (60,66,16) < color(x_1, x_2, x_3) <= (106,121,48)\}
\end{aligned}$$

The fuzzy set wherein LUV color space is employed for determining the degree of membership is defined as follows:

$$\begin{aligned}
&FuzzyLUV(x_1, x_2, x_3) = \\
&\{0, if color(x_1, x_2, x_3) < (18,98,143) \,\&\&\, if \ color(x_1, x_2, x_3) > (190,150,212), \\
&1, if \ (100,121,170) <= color(x_1, x_2, x_3) <= (110,131,180), \\
&((abs(18 - x_1) + abs(98 - x_2) + abs(143 - x_3))/3)/100, if \ (18,98,143) <= color(x_1, x_2, x_3) < (100,121,170), \\
&(((190 - x_1) + (150 - x_2) + (212 - x_3))/3)/100, if \ (110,131,180) < color(x_1, x_2, x_3) <= (190,150,212)\}
\end{aligned}$$

When the YIQ color space is employed for determining the degree of membership, the fuzzy set is defined as follows:

$$\begin{aligned}
&FuzzyYIQ(x_1, x_2, x_3) = \\
&\{0, if color(x_1, x_2, x_3) < (2,3,0) \,\&\&\, if \ color(x_1, x_2, x_3) > (122,140,133), \\
&1, if \ (55,65,61) <= color(x_1, x_2, x_3) <= (65,75,71), \\
&((abs(2 - x_1) + abs(3 - x_2) + abs(0 - x_3))/3)/100, if \ (2,3,0) <= color(x_1, x_2, x_3) < (55,65,61), \\
&(((122 - x_1) + (140 - x_2) + (133 - x_3))/3)/100, if \ (65,75,71) < color(x_1, x_2, x_3) <= (122,140,133)\}
\end{aligned}$$

The fuzzy set wherein LAB color space is employed for determining the degree of membership is defined as follows:

$$FuzzyLAB(x_1, x_2, x_3) =$$
$$\{0, if color(x_1, x_2, x_3) < (18,118,138) \&\& if\ color(x_1, x_2, x_3) > (190,157,105),$$
$$1, if\ (100,85,116) <= color(x_1, x_2, x_3) <= (110,93,126),$$
$$((abs(18 - x_1) + abs(118 - x_2) + abs(138 - x_3)) / 3) / 100, if\ (18,118,138) <= color(x_1, x_2, x_3) < (100,85,116),$$
$$(((190 - x_1) + (157 - x_2) + (105 - x_3)) / 3) / 100, if\ (110,93,126) < color(x_1, x_2, x_3) <= (190,157,105)\}$$

Another color space which is utilized to determine the degree of membership is the HSV color space and the corresponding fuzzy set can be defined as follows.

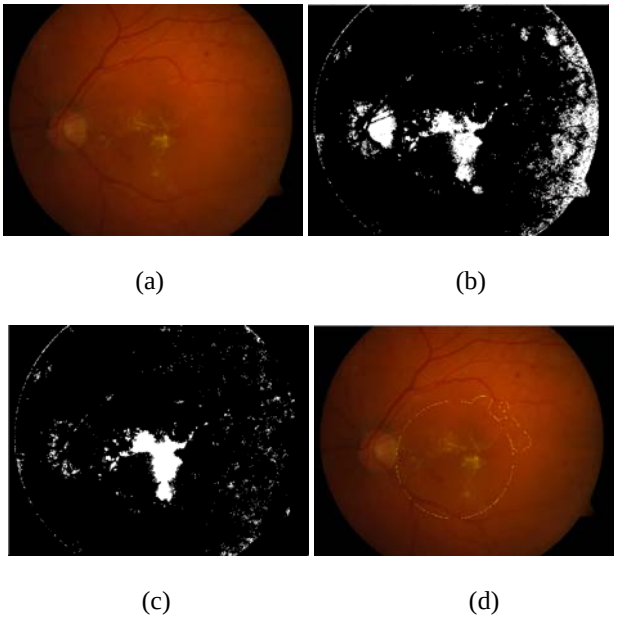
$$FuzzyHSV(x_1, x_2, x_3) =$$
$$\{0, if color(x_1, x_2, x_3) < (4,152,3) \&\& if\ color(x_1, x_2, x_3) > (25,254,182),$$
$$1, if\ (12,148,87) <= color(x_1, x_2, x_3) <= (17,158,97),$$
$$((abs(4 - x_1) + abs(152 - x_2) + abs(3 - x_3)) / 3) / 100, if\ (4,152,3) <= color(x_1, x_2, x_3) < (12,148,87),$$
$$(((25 - x_1) + (254 - x_2) + (182 - x_3)) / 3) / 100, if\ (17,158,97) < color(x_1, x_2, x_3) <= (25,254,182)\}$$

The converted color space values are fed as input to the corresponding fuzzy sets and the outputs are determined. The average of the five results is deliberated. The victim is diagnosed positive for Diabetic Retinopathy if the average is 1 and is tested negative if the average equals 0. All the intermediate averages denote the extent to which the victim is affected by the disease, for example when the average is .46 the person is said to have acquired 46% of the disease already.

5. Experimental Results

This section details the results of the automatic detection of hard exudates in diabetic retinopathy using morphological segmentation and fuzzy logic.

In this analysis, first the input features based on characteristic of exudates bright area, closely distributed cluster; white or yellowish color and strong edge were selected. Then Blood vessel and optic disc pixels were removed from the images in order to prevent misclassification by preprocessing. However, the algorithm still has some false detection because some pixels with similar color to the exudates belong to optic disc and edge of blood vessel. In our application we used a well known morphological segmentation operators and combined these in a novel way with fuzzy logic to detect the hard exudates in diabetic retinopathy. The results demonstrated here indicate that the system can help the ophthalmologist to detect the exudates in the screening process. Below the table: 1 shows the results for the detection hard exudates for different samples and Figure: 2 shows the result for the detection of hard exudates with preprocessing and morphological segmentation.

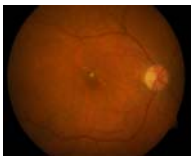
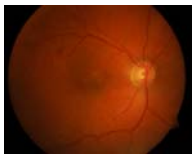
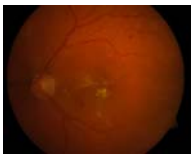
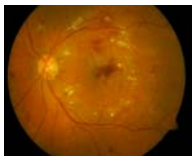


(a) (b)

(c) (d)

Fig. 2. Detection of hard Exudates in Diabetic Retinopathy (a) Original Image (b) Image after preprocessing (c) Image after morphological Segmentation (d) Results superimposed on the Original image.

Table: 1 shows the results for the detection of hard exudates using fuzzy logic for five different sample images.

Original image					
Segments classified as exudates using fuzzy logic.	14.77	20.92	7.99	81.39	97.13

6. Conclusion

Diabetic Retinopathy is the primary cause of visual loss and blindness in diabetic patients. Early diagnosis through regular screening and timely treatment has been shown to prevent visual loss and blindness. In this paper we have presented a novel approach to identify the presence of diabetic retinopathy from digital fundus images. The proposed work utilizes morphological operations for segmentation and fuzzy logic for the identification process. A variety of color spaces have been used in the formation of the fuzzy sets. The publicly available diabetic retinopathy dataset DIARETDB0 has been used in the evaluation process. The fuzzy rules derived using the proposed approach, have successfully detected the presence of diabetic retinopathy in digital fundus images. The results indicate that this system can facilitate the ophthalmologist to detect diabetic retinopathy in the early stage of diagnosis process.

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