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Advances in Bioresearch

ORIGINAL ARTICLE

Detection of Severity of Diabetic Retinopathy using Hierarchical Fuzzy System

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ABSTRACT
Diabetic retinopathy is an eye condition that damages the retina's optic neurons and eventually causes blindness. Visual acuity testing, pupil dilation, and Optical Coherence Tomography are some of the tests used to detect diabetic retinopathy. The intelligent system may assess the patient and then deduce a conclusion using a fuzzy inference model. With the help of simple graphical representations, the proposed hierarchical fuzzy expert system uses ten input parameters (intraocular pressure, visual field, visual acuity, blood sugar, high-density lipoprotein (HDL), low-density lipoprotein (LDL), hemoglobin glycated sugar (HBA1C), HB, blood pressure, and Triglyceride).The adaptive histogram equalization system was used to detect the pathological details i.e. hemorrhages, microaneurysm, exudates, and Blood vessels.On 10 factors and the findings of the fundus picture, the expert system recognizes normal eye, diabetic retinopathy (Mild), diabetic retinopathy (Moderate), and diabetic retinopathy (Severe) with higher efficiency and lower cost of calculations task.The entire segment of tests was performed on a fuzzy system under the supervision of an ophthalmologist. The accuracy, sensitivity, and specificity of the designed system are found to be 98%, 97%, and 100%. Moreover, the results of systems were verified with the results of the traditional approach of the ophthalmologist.
Keywords: Hierarchical Fuzzy Expert System, Graphical User Interface, Image Processing,Diabetic Retinopathy.

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INTRODUCTION

In the healthcare unit, health analysis of ailment is one of the very important matters. The health check industry is one of the principal fields that involve engineering technologies to the way in vague information neutrally [1-2]. Artificial intelligence has been the subject of rigorous research using a variety of computing technologies, including fuzzy logic, artificial neural networks (ANNs), and genetic algorithms [3].To hold the real-life vague state of affairs, all these methodologies effort jointly and give flexible information capabilities from one form to another. An apparent becoming class of intelligent machines that hold the capability to aid physicians in diagnosis procedures is the progression of a clinical diagnostic decision support system [4].At the moment medical science in addition to technology is taken under consideration to be parallel ways. An explanation is provided to discuss the medical problems. They are offered in the most effectual and competent style as per the technological scenario. Diabetes causes blindness due to prolonged high blood glucose levels in people around the World. Other complications of diabetic retinopathy include oxygen deprivation in the retina and irregular blood vessel growth [5-6].Diabetic eye disorder is done by the irregular level of glucose in the blood that occurs itself within the eye membrane (retina).When a high glucose level reimburses the minute arteries that deliver nutrients and oxygen to the tissue layer, diabetic retinopathy develops [7]. These blood vessels may swell or seal shut, preventing blood from flowing through them. Sometimes nonstandard blood vessels develop on the surface of the retina. These alternations can steal your visualization [8-9].Proliferative diabetic retinopathy and non-proliferative diabetic retinopathy are the two types of diabetic eye disease [10]. Diabetic retinopathy was detected in 4.06 million Americans in 2000. This number climbed to 7.69

million in 2010 and is expected to rise to more than 14 million by 2050. Diabetic retinopathy affects an estimated 93 million people worldwide [11].
Initially, recognition of diabetic retinopathy helps to overcome blindness. Eyesight examination tests are being done to find out diabetic retinopathy but the process is tedious [12-13]. As a product of this cause, for the determination of diabetic retinopathy at the early stages there is a basic necessity to build up further precise and low-cost masterpieces. So, preprimary stage diabetic retinopathy recognition could be one of the most useful applications with the ability to detect diabetic retinopathy in its early stages [14]. This research reveals a fuzzy expert system and Adaptive histogram Equalization which is based on fuzzy rules and fundus images. Owning the powerful lead yields improved outcomes. The biggest benefit of the fuzzy inference system framework is the way that analysts can represent as well as reform uncertain, complicated frameworks into the uncomplicated human comprehensible structure by handling human perception and education as a fuzzy guiding principle as locating linguistic elements [15-17].This research mentions a master structure by assembling fuzzy set judgments to infer diabetic retinopathy from its suggested indications. With medical specialists' data, fuzzy standards are put forth for a bit more superior cognitive practice. For decisions ondiabetic retinopathy,this paper provides information based on the expert structure [18-20]. A fuzzy intrusion system was organized to implement the results for the assessment of diabetic retinopathy. This system was armed with ten variables of diabetic retinopathy. Using therapeutic expert information for a significant patient's condition and making an accurate conclusion is dependent on fuzzy guidelines [21-23].
A hierarchical fuzzy expert system and adaptive threshold equalization techniques have been revealed in this research, based on fuzzy rules and fundus images. About the powerful pilot, it yields an improved outcome. The way that the analysts can represent as well as reform vague, convoluted framework into an unfussy human intelligible structure by handling human perception and education as a fuzzy guiding principle as the locus of linguistic elements is the biggest benefit of the fuzzy inference system framework. Detection of Severity of Diabetic Retinopathy is indeed a critical challenge in the modern era. In this research, an adaptive histogram equalization system was used to detect the pathological details i.e. hemorrhages, microaneurysm, exudates, and Blood vessels in a more accurate manner.

MATERIAL AND METHODS

After a thorough literature survey and meeting with the domain experts and doctors, ten input parameters have been used to detect diabetic retinopathy with high precision. Intraocular pressure, visual field, visual acuity, fasting blood sugar, low-density lipoprotein (LDL), high-density lipoprotein (HDL), hemoglobin (HB), blood pressure, HBA1C, and triglyceride are the 10 important variables employed for this purpose. These input parameter values are put to use for predicting the status of an eye. Following the selection of the input variables, the next step is to fuzzify the variables, which entails determining the fuzzy sets for each input parameter and their corresponding choice of belonging to each fuzzy rule set.

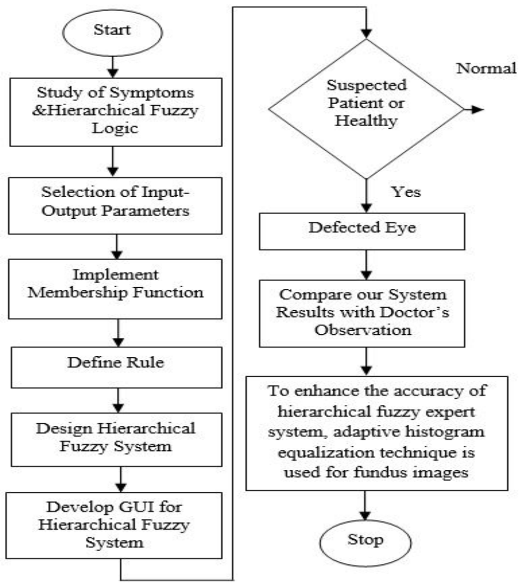


Figure: 1 Method for Implementation of Proposed System

Based on the rules developed in .fis files fuzzy inference system) gives an accurate result, thus the hitch of MATLAB installation is uninvolved by making the .exe file of our expert system. To enhance the accuracy of the hierarchical fuzzy expert system, the adaptive histogram equalization technique is used for fundus images to detect Microaneurysms, hard exudates, Neovascularization, and Hemorrhages. Figure 1 depicts the method for implementation of the proposed system.
Intra-ocular pressure, visual field, visual acuity, fasting blood sugar, low-density lipoprotein (LDL), high-density lipoprotein (HDL), hemoglobin (HB), blood pressure (BP), HBA1C, and triglyceride were chosen as input variables for the expert system with the help of ophthalmologists and after reviewing the literature. Figure 2 shows the block diagram of input-output variables of a hierarchical fuzzy expert system.The files of '.fis'are made in a fuzzy inference system for 'Diabetic Retinopathy' the precise result has been given by the system for both left and right eyes separately.

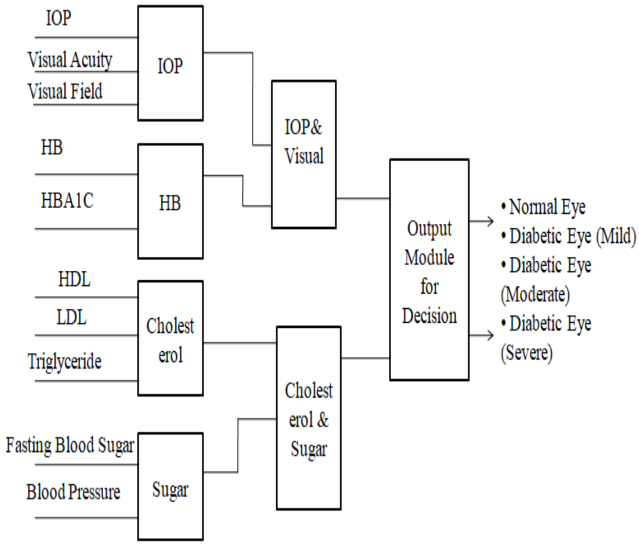
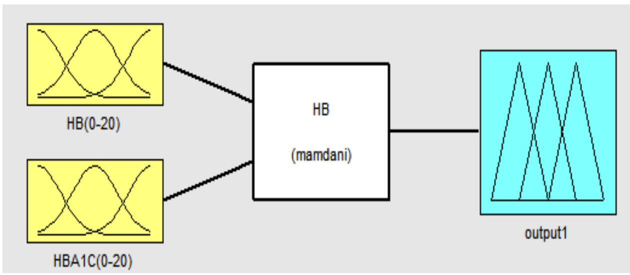
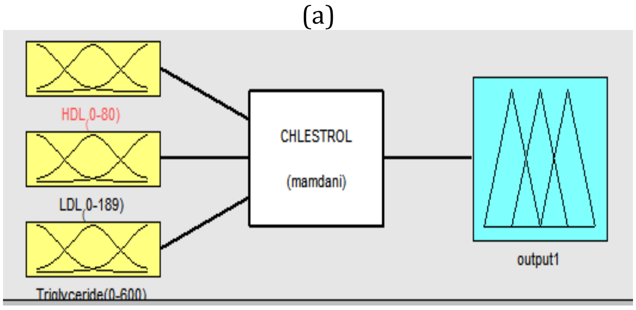


Figure: 2 Block diagram of a Hierarchical fuzzy expert system

Figure 3(a) depicts .fis1 file (HB) including two input parameters i.e. (HB/HBA1C). Figure 3(b) depicts the file of '.fis3'(Cholesterol) including three parameters i.e. LDL, HDL, and Triglyceride. Hence, two .fis files are depicted below.



(a)



(b)

Figure 3: Hierarchical FIS with 10 inputs & 1 output. (a) Fis file of HB and HBA1C and b)Fis file HDL, LDL, and Triglyceride

Membership Functions:

Each input variable has a membership function associated with it. As a result, the relationship functions of parameters are revealed in this research below portrays the unambiguous outline of the membership functions.

Figure 4 shows the membership function of Intraocular Pressure (IOP) which comprises three Membership plots namely: Low (hypotony), Normal eye pressure, and High (Ocular hypertension). Figure 5 shows the membership capacity of Disc i.e. Fasting Blood Sugar which comprises three Membership plots Low, Normal, and High. A triangular membership function trimfis operated for the input trait and a trapezoidal membership function is operated for the output attribute.A triangular membership function is used to observe the peak point value and a trapezoidal function is used to decide the full output range.

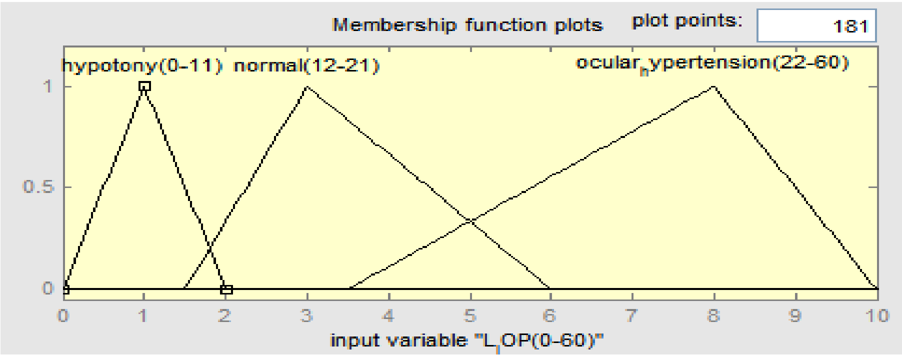


Figure: 4 Membership function of Intraocular Pressure

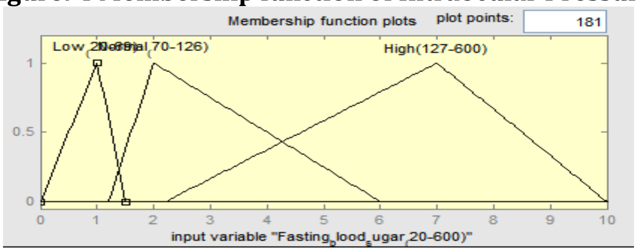


Figure: 5 Membership function of Fasting Blood Sugar

Rule Editor:

Explaining the input of the pattern, is known as a "fact list" and can be modified through the rule editor. Rule editor encompasses a huge editable textual field for exhibiting and writing rules [21]. Figure 6 displays the rules of fis 1 i.e. twenty-seven rules for HDL, LDL, and Triglyceride. The formula to make the rules is:

Rules = Mi

M = Membership function

i = Input Parameters

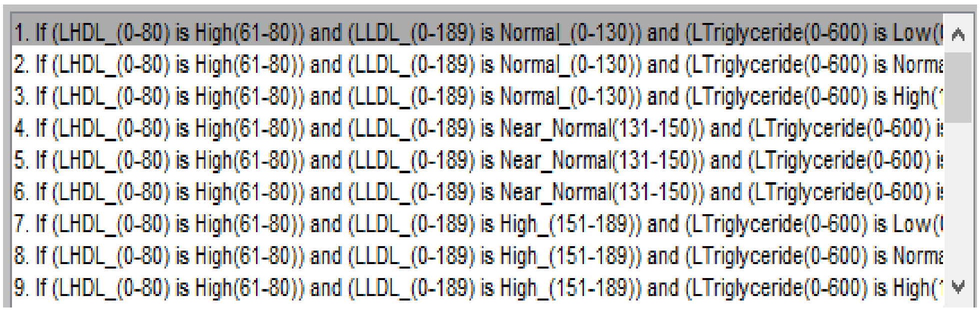


Figure: 6 Rule Editor

Fuzzification and Defuzzification:

Fuzzification and Defuzzification play a very role in the Fuzzy Inference System. Fuzzification is the process of converting the crisp input into a fuzzified output and Defuzzification converts the fuzzified value into a crisp value. In the proposed system, the Centroid method is used for Defuzzification.

Rule Viewer:

Rule viewer is involved inthe investigation of the fuzzy inference system. The output of this examination is anindicator for results verificatione.g. the appearance of the unit membership function involves the result.The entire fuzzy inference method's information is revealed by the rule viewer. The menu bar and status line are personal items in accumulation.The specific input value can be entered in the text field made available at the lower right location while framing. There is a text field in the bottom right, where we can submit a specific input value. Figure 7 represents a rule viewer of the projected organization displayed. It shows the result of the whole fuzzy system. On the left plane (Near the crest), the results are as follows "17.8" (Value of Defuzzified) which means the normal value for a person found by the system.

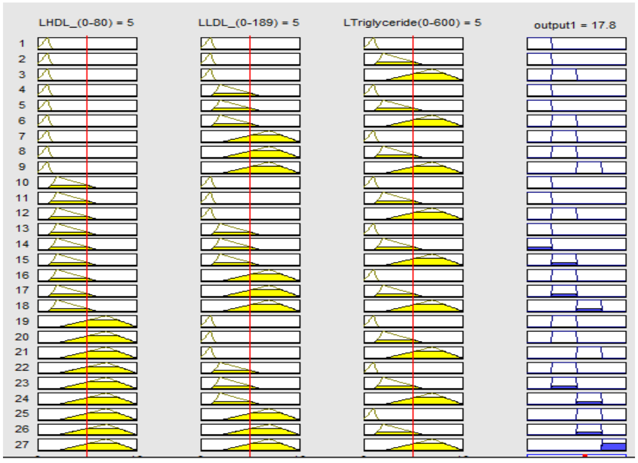


Figure: 7 Rule Viewer

Surface Viewer:

For evaluating the dependence of any one output on 1 or 2 of the inputs Surface viewer is used, for the fuzzy inference system (FIS) it spawns and devises an output surface plot. Figure 8 shows the surface plot of the disease between two symptoms HDL and LDL. The graph shows that when the range of angle is between 0 to 10 and intraocular pressure is between 0 to 10 then there is a disease will be recognized. The blue and yellow colors indicate Input and output respectively.

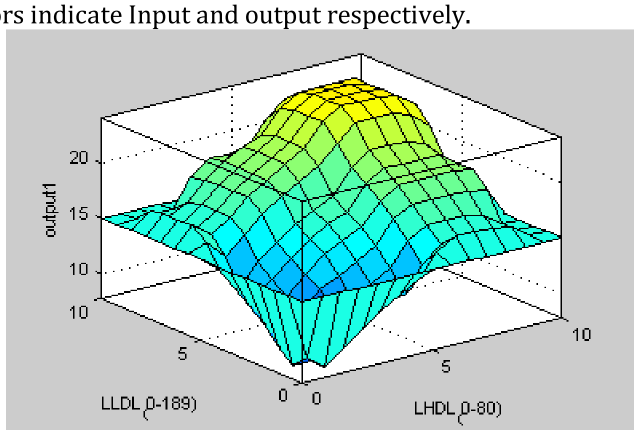


Figure: 8 Surface view of HDL and LDL

Graphical User Interface:

On experts' demand, we developed a Graphical User Interface (GUI) to make it simple and easy to use for ophthalmologists as shown in Figure 9.

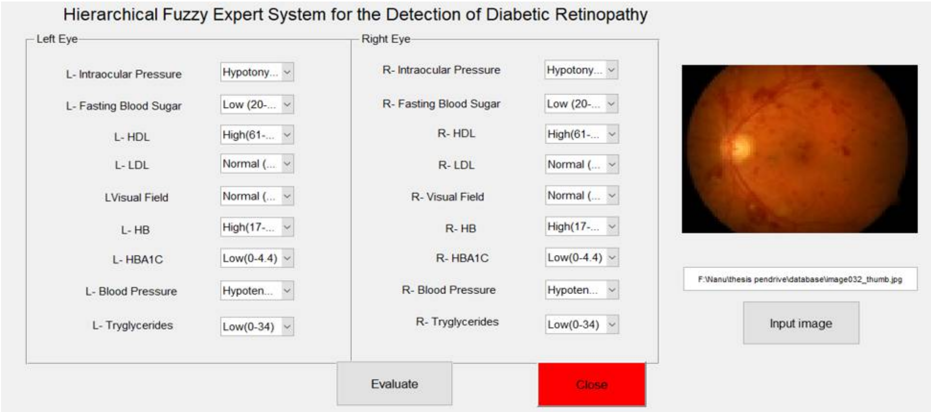


Figure: 9 GUI for Hierarchical Fuzzy Expert System

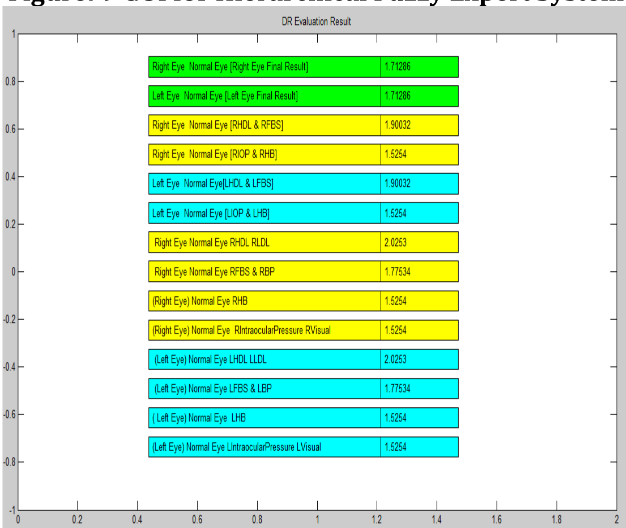


Figure: 10 Diabetic retinopathy Evaluation Result

Intra-ocular pressure, visual field, visual acuity, fasting blood sugar, low-density lipoprotein (LDL), high-density lipoprotein (HDL), hemoglobin (HB), blood pressure (BP), HBA1C, and Triglyceride are among the 10 input parameters for diabetic retinopathy shown in Figure 9.Graphical User Interfaceis connected with .fis files and helps the user interface easily while providing inputs to achieve the results as per the rules. Figure 10 depicts the diabetic retinopathy evaluation result of each layer of the hierarchical fuzzy system separately i.e. for a left eye and right eye.

Figure: 11 Illustrates the Graphical User Interface for the fundus image.

Figure 11 represents the Graphical User Interface for the fundus image to classify a normal eye image, an image with diabetic retinopathy eye by using the adaptive histogram equalization method. A massive amount of retinal online fundus image catalog is acquired nowadays, and several of the database image sources are contributed freely to follow a line of investigation purpose. Figure 12 shows input fundus images.

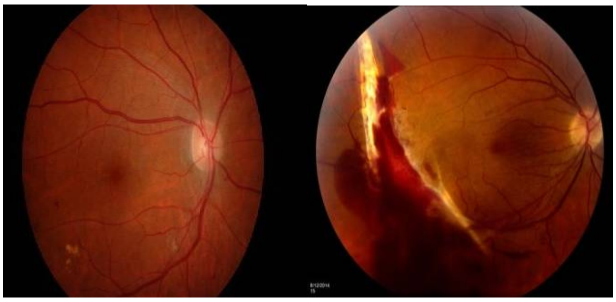


Figure: 12 Input fundus images

The ocular images captured by the fluorescent oscilloscope are a lot noisy and have bad contrast. It is making it seriously difficult for doctors to detect intrinsic abnormalities in the eye.Adaptive Histogram equalization is a type of histogram that adapts to improve the diagram, followed by 2 D median filtering. This is utilized to give smoothness to back diabetic retinopathy op in similarities and taking the ability to cut down the noise of impulse which does not produce the idealistic pixel strength.

Input Fundus Eye Images:

Adaptive histogram equalization (ADHE) is utilized to step forward contrast in an image.It is an image processing performance on a mainframe. Because of its adaptive nature, it computes a large number of representation histograms and uses them to change the image's intensity principles. ADHE is consequently, additionally applicable for rising the regional distinction and edge augmentation in all and every county of the fundus eye image. Following arethe steps of fundus image enhancement as shown in Figure 13.

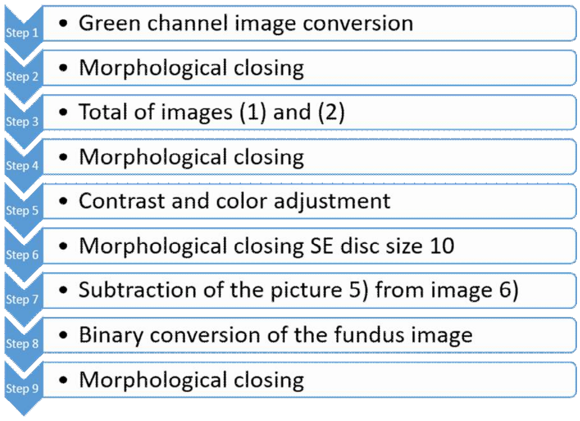


Figure 13: Illustrates the Steps of fundus image enhancement are:

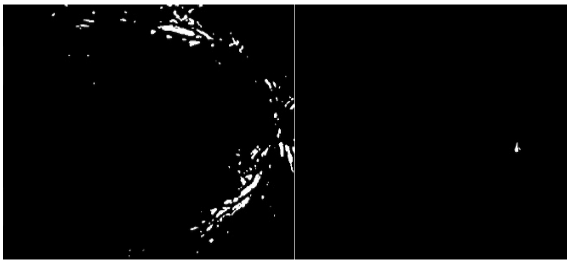
Microaneurysms:

Microaneurysms are the abrasion that may subsist professed at near the beginning stages of healing, the restricted annex of retina capillary and therefore the outpunching of tube parapet determined when diminutive fleck that are petite in mass and encircling in character. Small aneurysms are small patches of a balloon-like bulge in the blood vessels that are difficult to distinguish from supplemental aberrations such as spilt blood due to their insignificant quantity and red blackness.Micro aneurysms are not necessarily everlasting; they move toward the vision for a certain phase of time and grow fainter gone. Detected microaneurysms are made known in Figure 14.

Figure: 14: Detected Microaneurysms

Exudates:

Hard exudates abscess is yellow acne speckled in retina commonly in the subsequent extremity close to macula recurrently give the impression in clusters or dirt-rings and are collecting lipid break-down yield from smashed blood vessels. It is minute in volume perceptible sallow, light yellow-white, or boring white with fluffy restrictions, often performance striations corresponding to the bravery fiber layer are the lesions incorporated. Detected exudates are shown in Figure 15 (a) and normal exudates depict in Figure 15 (b).



(a) (b)

Figure: 15 Hemorrhages: Illustrates (a) Detected exudates and (b) Normal exudates.

The areas of Hemorrhages are evaluated by the anticipated classification as shown in Figure 16. Retinal hemorrhage maybe anarchy of the human eye within which hemorrhage happens into the luminosity receptive tissue on the reverse barrier of the eye. Hemorrhages can be caused by hypertension or diabetes mellitus (DM).

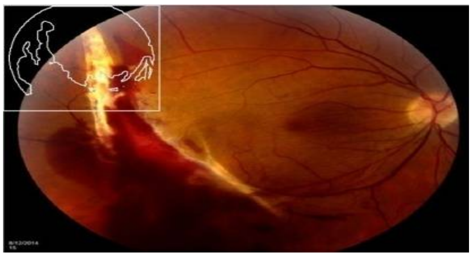
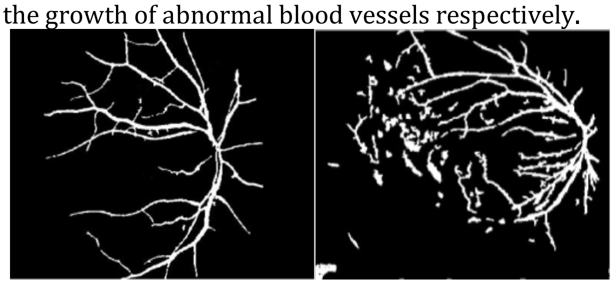


Figure 16: Detected Hemorrhages

Neovascularization:

Corneal Neovascularization is the creation of realistic minute vascular networks and viewed the new-fangled blood vessels, it makes difference in initial angiogenesis and is categorized by an annex of tube buds, protrusion, and bunch from already existing blood vessels. Figure 17(a) and Figure 17(b) depict the normal blood vessels and the growth of abnormal blood vessels respectively.



(a) (b)

Figure: 17 Illustrates (a)Normal blood vessels and (b) Shows detected blood vessels

Microaneurysms, exudates, hemorrhages, and neovascularization can all be detected in fundus imaging.The extracted features are evaluated from a database of about 140 images. The samples are collected from the Jalandhar and Ludhiana hospitals. The Fuzzy Logic System (FLS) was used to classify fundus images as either diabetic retinopathy or normal.

PROCEDURE

Tools used:

For validation of the system, Hierarchical Fuzzy Expert System (HFES) was used in contrast to the Ophthalmologist Grading System (OGS). According to the statistical null hypothesis, there is no significant difference between the mean Eye disease scores and a control group of different domains.

Data collection:
Initial information about patients exaggerated by the diseases under concern was gathered from the hospitals around Jalandhar and Ludhiana region. The data consists of eye diseases i.e. Diabetic retinopathyas well as Normal cases of patients.

Data analysis:
The dataset was evaluated through the System Programming and System Simulation tool and an investigation has been done to standardize the HFES. The analysis of variance (ANOVA) test was performed to calculate the mean/standard deviation of the investigational and control groups, as well as to infer several differences.

Validity:
For validation, HFES was contrasted with the Ophthalmologists Grading System (OGS).

Discriminant function analysis:
This was developed to investigate the magnitude of Eye diseases that might be precisely classified by the Hierarchical Fuzzy Expert System (HFES).

Sensitivity and Specificity:
Sensitivity and Specificity of Hierarchical Fuzzy Expert System (HFES) were calculated. The ability to identify a condition, such as diabetic retinopathy or diabetic retinopathy eye, is referred to as sensitivity. The capacity to recognize a normal eye as such is known as specificity.

RESULTS AND DISCUSSIONS

Validity:
The value of the Mean score for cluster sickness (125.7) is measured at the head of that of the normal group (59.1). The variations for mean were statistically significant i.e. ($p< 0.001$). So that is the reason, the acceptance of the statistical null hypothesis is declined. The same scenario was in the Ophthalmologists Grading System (OGS) with decreased accuracy, moreover, using manual techniques the time consuming is more. For each of the ten domains of the Hierarchical Fuzzy Expert System (HFES), the mean values were statistically completely different between the 2 study clusters (Table 1). This means that HFES tell the difference between Eye disease and normal peoples, therefore its validity is established.

Table: 1The mean values for each of the 10 inputs of the Hierarchical Fuzzy Expert System (HFES) were compared to the Ophthalmologists Grading System (OGS)

Sr.No.	Domain	Group	N	Mean	SD	F- Value
1	IOP	Diabetic Retinopathy	70	15.3	1.6	
		Normal	70	6.6	0.1	825.23#
2	VA	Diabetic Retinopathy	70	13.4	0.95	
		Normal	70	5.22	0.75	1880.15#
3	HB	Diabetic Retinopathy	70	13.9	2.5	
		Normal	70	6.61	0.6	245.68#
4	HBA1C	Diabetic Retinopathy	70	12.3	1.75	
		Normal	70	5.25	0.85	520.25#
5	HDL	Diabetic Retinopathy	70	11.5	1.5	
		Normal	70	4.96	0.73	570.77#
6	LDL	Diabetic Retinopathy	70	10.4	0.76	
		Normal	70	5.56	1.2	540.44#
7	Triglyceride	Diabetic Retinopathy	70	12.6	1.56	
		Normal	70	6.4	0.64	456.23#
8	FBS	Diabetic Retinopathy	70	13.1	1.85	
		Normal	70	6.5	0.75	580.56#
9	BP	Diabetic Retinopathy	70	10.6	5.6	
		Normal	70	5.6	1.3	275.58#
10	Visual Field	Diabetic Retinopathy	70	12.6	1.56	
		Normal	70	6.4	0.64	456.23#
	HFES	Diabetic Retinopathy	70	125.7	9.53	
		Normal	70	59.1	4.93	1430.3#
	OGS	Diabetic Retinopathy	70	64.45	7.25	
		Normal	70	20.23	1.45	1655.24#

# indicates $p < 0.001$ level of significance

Discriminant Analysis:
This investigation was utilized to observe the quantity of Diabetic retinopathy in ordinary cases and may be appropriately classified by Hierarchical Fuzzy Expert System (HFES). This investigation calculated accurately Hierarchical Fuzzy Expert System (HFES) may distinguish the usual management cluster from diabetic retinopathy cases. This result illustrated that it had been ready to classify properly 98% of diabetic retinopathy and normal eye. A 97 percent sensitivity and a 100 percent specificity were achieved (Table 2 below).In the same way, the discriminant analysis also evaluated however accurately OGS may recognize the difference between the normal control groups from eye disease cases and therefore the results displayed that it had been ready to classify properly 96% of eye disease & normal. The sensitivity achieved was 94% and the specificity achieved was 97% (Table 3below). It's been displayed for a similar sample, Ophthalmologists Grading System (OGS) was precisely less.

Table: 2Discriminant Analysis using HFES

Group		Eye Disease		
	N	Diabetic Retinopathy	Normal	Total
Diabetic Retinopathy		68	2	70
Normal		0	70	70
Diabetic Retinopathy	% Age	97	3	100
Normal		0	100	100

Table: 3Discriminant Analysis using OGS

Group		Eye Disease		
	N	Diabetic Retinopathy	Normal	Total
Diabetic Retinopathy		66	4	70
Normal		2	68	70
Diabetic Retinopathy	% Age	94	6	100
Normal		3	97	100

Table: 4:HFES accuracy comparison with previous studies

Sr.No.	Author (year)	Accuracy (%)	HFES Accuracy (%)
1	8]	93	98
2	[10]	93.5	
3	[19]	89	

Table 4 depictsthe relative accuracies of HFES matching to earlier heuristic research that proves HFES to be additional precision.
By using formulas, we can easily find out the accuracy, sensitivity, and specificity of designed HFES. The number of right decisions divided by the total number of patients equals the accuracy.

$$Accuracy = \frac{\text{Total No.of correct decisions}}{\text{Total No.of patients considered}} \text{ x } 100 \quad (1)$$

$$Accuracy = \frac{138}{140} \text{ x } 100$$

Accuracy = 98%

The proportion of True Positives to the sum of True Positives and False Negatives is known as sensitivity [19].
TP -Diabetic retinopathyis classified as Diabetic retinopathy
FN - Diabetic retinopathyis classified as non-Diabetic retinopathy.

$$Sensitivity = \frac{\text{True Positive(TP)}}{\text{True Positive(TP)} + \text{False Negative(FN)}}$$

(2)

$$Sensitivity = \frac{68}{68+2} \times 100$$

Sensitivity= 97%

The proportion of True Negative to the sum of True Negative and False Positives is known as specificity [19].

TN - Normal image is classified as Normal FP – Normal fundus image is classified as Diabetic retinopathy image.

$$Specificity = \frac{\text{True Negative(TN)}}{\text{True Negative(TN)} + \text{False Positive(FP)}}$$

(3)

$$Specificity = \frac{70}{70+0} \times 100$$

Specificity = 100%

The doctors reassured the ratings in these meticulous fields to have classified outputs.

CONCLUSION

Diabetic retinopathyisa widely spread eye disease nowadays. So it must be detected at an early stage. Early detection enables doctors to identify Normal eye and Diabetic Retinopathy. This research reveals a fuzzy expert system,auto masking, and ROI detection technique which are based on fuzzy rules and fundus images. It is determined whether a person has healthy eyesight or Diabetic retinopathy using these rules and extracting features from fundus photos.By having the outcomes of both as per the data of Diabetic retinopathywe got 98% accuracy.This work can be increased by putting in more inputs and also by using Universal ICD 10 codes. Age factors, hereditary relations, and treatment are not to be considered in our mechanism. It will be a boon for society if an Android App is created to detect diabetic retinopathyand treatment suggested for them is included in the system. Thus, this technology will enhance the future.

SIGNIFICANCE STATEMENTS

This study aims at developing an easier, quicker, and more affordable system for the detection of Diabetic Retinopathy. Even if an ophthalmologist has only a few of the ten examinations in hand, then also they can find out if a patient has a problem or not. This makes this research valuable for ophthalmologists and also for common people. After this, the ophthalmologists can easily decide if there is any need for further examination for getting a clearer picture depending on the results of the Hierarchical Fuzzy expert system (FIS). This system also depicts how severe Diabetic retinopathyis for both eyes (Left and Right eye) separately i.e.

Normal eye

Diabetic retinopathy(Mild)

Diabetic retinopathy(Moderate)

Diabetic retinopathy(Severe)

The tests for detection of Diabetic retinopathyare really expensive and time-consuming. Hence our study will overcome this limitation. This research involves ten parameters i.e., Intra-ocular pressure, visual field, visual acuity, fasting blood sugar, HBA1C,Hb,BP,LDL,HDL and Triglyceride. Earlier studies and researches involved a maximum of two parameters which provide lesser accuracy. Easier, quicker and cheaper recognition of both diseases can be arrived by utilizing the projected fuzzy interference framework.

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CONFLICT OF INTEREST

There is no potential for a conflict of interest in the publication of this material.

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