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PERFORMANCE ANALYSIS OF COMBINATORIAL FILTER MODEL FOR DRUSEN ENHANCEMENT

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ABSTRACT

Background: Age related macular degeneration is one of the retina disease that affects vision of aged people. One such retinal disease is caused by drusen deposits in human eye. Many eye care hospitals need drusen enhancing system integrated into retina eye screening system for diagnosis of AMD in human.

Methods: This research article presents a study in drusen enhancement model in retinal fundus image of AMD patients. The model is developed using image filters and fuzzy inference system applied on fundus images to enhance drusen exudate features. It is applied, tested and evaluated on images from a private database and STARE database. This research article discusses the performance of the combinatorial filter model with statistical tests.

Results: The statistical test results are compared with a few enhancement methods to understand the performances. The quality features such as Sensitivity, Specificity, Accuracy, Precision and F1-Scores are measured and the error values are also measured with Mean Square Error measure.

Conclusion: These results show that AMD drusen features are enhanced with 95% of accuracy with average error 0.0025.

Keywords: Drusen, Filter, Fundus, Fuzzy inference system, Image enhancement

1. INTRODUCTION

Age-related Macular Degeneration (AMD) is a retina disease in human eyes that affect the vision of people. Certain type of this disease is developed as lesions which are yellow in color which is below the retina. The drusen is developed in the center region of retina which is known as macula. These retina lesions are developed by waste proteins which is transformed to a lesion known as drusen. The proteins are deposited between Bruch's membrane and Retinal pigment epithelium portions beneath the macula. Clinically, different types of drusen elements are classified as hard and soft types. Hard drusen elements appear as a small lesion with visible strong boundary and the soft drusen lesions appear with indistinct boundary[1, 2].

The severity of these ailments may cause loss of vision in many people[2]. To treat the patients with this complaint, the hospital captures fundus images of their eye. The optometrist observes and infers the images to understand more about the illness in patients. These information is used to treat the patients appropriately to prevent further spread of the disease. The ophthalmologists can make a good diagnosis if the drusen elements are enhanced appropriately. The diagnostic information will be closer to better diagnosis and complete if the drusen elements are enhanced in a more readable manner. This research work proposes a performance evaluation for an enhancement model.

1.1 Objectives

The primary objective of this research work is to understand the objective assessment of drusen enhancement with the statistics behind the data. The objective is also to assess the performance of the combinatorial filter model for image enhancement and error measurement comparing with other models.

2. MATERIALS

This research used a total of 120 images from two different AMD fundus image data sources. The first source is the private source consisting of 95 images and the other data source is STARE data set. The MATLAB tool is used to implement the combinatorial filter model to enhance drusen.

3. METHODOLOGY

The methodology involves three important steps in drusen enhancement model building. As it is understood that in a conventional image processing methodology, the steps involved in this research work are initial preprocessing, bit planar preprocessing and model building.

3.1 Drusen Enhancement Model

A drusen enhancement model is developed by applying filter components on the fundus image greyscale bit planar images followed by applying fuzzy logic system on the resultant images. The model is known as combinatorial filter model abbreviated as CFM[4]. The model is represented in equation 1.

$$EI = OI + FIS(SP7, SP4, SP5) * Reconstructed(Filter(SP7, SP4, SP5)) \quad (1)$$

where EI is the Enhance Image, OI is the original image, FIS is the fuzzy inference system evaluation, SP7 is the first significant 7^{th} bit planar image, SP4 is the second significant 4^{th} bit planar image and SP5 is the third significant 5^{th} bit planar image. The Filter function applies three set of filters on SP7, SP4 and SP5 independently and the Reconstructed function reconstructs the filtered bit planar images with rest of the insignificant bit planar images. The image gets enhanced when it is fused with reconstructed image and original image[3]. The matrix structure filter applied for bit 4^{th} planar and 5^{th} bit planar images are shown below as

$$SP5 \rightarrow \begin{matrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{matrix} \qquad SP4 \rightarrow \begin{matrix} 1 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{matrix}$$

3.2 Model Development Approach

The authors implemented filters on drusen significant bit planes to enhance regions of drusen features in retinal fundus images. A model was developed by implementing fuzzy inference system based image processing technique on the planar image with drusens. The approach includes Pre-processing, Bit Planar Processing and Fuzzy Based Processing[4].

3.2.1 Pre-processing

The ultimate purpose of pre-processing is to prepare the image that paves way for easy identification of the respective lesion regions in the retina. The original color fundus image is converted into grayscale image to enable easier application of image enhancement. The pre-processing step in any image enhancement methodology involves use of image filters[5]. The model developed in this study uses multiple filters to pre-process the image data. The first level of pre-processing involves a predefined median filter. The next level of pre-processing involves user defined filter created with a suitable filter matrix. This level is explained in the Bit planar pre-processing section.

3.2.2 Bit planar Pre-processing

All bit planar images are segregated from greyscale fundus image with the objective to find the drusen intense bit planes. The significance of the drusen is subjectively found to be in the 7^{th} planar 5^{th} planar and 4^{th} planar images. The finite impulse response filter operation is applied on these planar images with a convolution function. The function convolves pixel values with the 3 by 3 matrix to generate new pixel values. The 3 by 3 filter matrix is created with the trial and error method.

$$SE51 \rightarrow \begin{matrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{matrix} \qquad SE41 \rightarrow \begin{matrix} 1 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 1 & 0 \end{matrix}$$

3.2.3 Fuzzy Based Processing

The filtered bit planar images are processed with a fuzzy inference system. The system incorporates a set of fuzzy rules that creates the enhanced image with more legible drusen portions. The purpose of fuzzy implementation is to enhance the pixels of drusens while smoothening the enhancement. The major steps involved in this fuzzy system approach are fuzzification and defuzzification. In the fuzzification step, the input pixels in the bit planar image is transformed to fuzzy output values. In the next step, that is during defuzzification the aggregation technique is used to find crisp values from fuzzy output values. The membership functions play a significant role in determining if the pixel is a member of either of the four drusen categories, which is done by applying fuzzy rules to the output values. The four categories of drusens are Non drusen, Weak drusen, Normal drusen and Strong drusen; abbreviated as NonD, WD, ND and SD respectively. The figure 1 shows the process of model building.

The algorithmic steps in model building process is described in section 4.2.4.

3.2.4 Algorithmic Steps

1. Input color image
2. Preprocess the image with a reference image using histogram specification
3. Extract planar images and find significance of drusens in each planar image
4. Apply matrix filter on 4^{th}, 5^{th} & 7^{th} planar significant images with drusens and reconstruct the image
5. Input the reconstructed image to the fuzzy inference system
6. Apply fuzzy rules to enhance the drusen image

4. RESULTS AND DISCUSSION

To understand the performance of this model, various statistical tests are performed. The tests include statistical moments such as mean, variance and standard deviation with the following objectives. First, the variability of pixel intensity in enhancement is tested by comparing the pixel values before and after processing the image regions with the box and whisker plot.

4.1 Variability of Pixel Intensity in Enhancement

The important purpose of this evaluation is to find the effect of enhancement on different intensity level pixels in the image. This is observed with Minimum, Quartile1, Median, Quartile2 & Maximum values in a Box and Whisker plot. The interquartile range is shown as the boxes in all six image region representations. Following are few observations in the box plots as depicted in figure 2. These plots clearly show that the pixel values are enhanced after processing the image regions with the model as shown in figure 1, which indicates that the pixel values are enhanced after processing. Moreover, the minimum values of pixels in all the post processing plot is greater than the pixel values in the pre-processing counterpart. This is also true in case of maximum and median values of the plots.

The Median summary statistics is considered to find the effect of processing that is shown in Table 1. The table shows that the average of median differences is 0.147 which is the enhancement effect. In other words, this can also be interpreted that the image regions are enhanced by 14.7%. The table also shows that the range of enhancement is from 17.8% to 10.9% which is the highest and lowest median differences respectively.

4.2 Performance Analysis

The statistical measures such as sensitivity, specificity, accuracy, precision and F1-score are measured for the image regions. Sensitivity describes an actual drusen identified correctly as drusen. Specificity describes an actual non-drusen correctly identified as non-drusen. Accuracy explains the nearness of correct enhancement and. Precision is the nearness to measurements. F1-score is a measure of precision and sensitivity. The table 2 shows the measure values of the model evaluation parameters for ten different image region enhancements along with the averages.

4.3 Comparison of Methods

A few models' performances are compared with the performance CFM model. Table 3 shows the comparison of Sensitivity, specificity and accuracy measures along with precision and F1-score.

The performance accuracy is tested with sensitivity, specificity, accuracy and found that sensitivity and accuracy measures are 91% and 95% which is better than other enhancement models as shown in Table 3. However, if the data is imbalanced, then the precision and F1-Score measures are significant in measuring the performance, which is calculated as 97% and 94% respectively. In13, the authors of the article proposed a system to classify AMD in private data set with an accuracy of 90.19%.

4.4 Mean Squared Error and Image Enhancement Factor

The mean squared error measure is calculated for the original image and the enhanced image by using the average of squares of errors. The formula for MSE is $MSE = \frac{1}{mn}\sum_{i=1}^{m-1}\sum_{j=0}^{n-1}[I(I,J)-(k(I,J)]^2$, where m, n are rows and columns respectively in the image matrix. The letter I denotes the original image and K denotes the enhanced image. The table 4 shows MSE and IEF values calculated using original image and enhanced image as parameters in the model implementation. The IEF is calculated by using the formula $IEF = \frac{\frac{1}{mn}\sum_{i=1}^{m-1}\sum_{j=0}^{n-1}[I(I,J)-(\eta(I,J)]^2}{\frac{1}{mn}\sum_{i=1}^{m-1}\sum_{j=0}^{n-1}[I(I,J)-(k(I,J)]^2}$ where η is the noisy image that is created as a intermediary.

The Mean Square Error and Image Enhancement Factor values are shown in table 4. The average error is 0.00283 for private data and 0.00236 for public data. The values indicate that the error is almost negligible. But subjectively, when an enhanced image is observed, the portions remarkably enhanced are mostly drusens, which are specific regions of interests. The IEF shows the factor of image region enhancement. The average IEF for private data is 4.89 and that of STARE images is found to be calculated as 5.28. After enhancement, the higher the IEF values, higher the enhancements.

Table 5 shows that the MSE is found to have average of 0.002595, which is lesser than 0.048 calculated for private data set.

5. CONCLUSION

The authors proposed performance evaluation of a drusen enhancement filter model known as combinatorial filter model. The model composed application of filters on drusen significant bit planar images and fuzzy inference system. The research study proves the variability and median difference of pixels compared with pre and post processed enhanced drusen elements. The tests also include assessing sensitivity as 0.91, specificity as 0.88, accuracy as 0.95, precision as 0.97 and F1-sccore as 0.94. The sensitivity and accuracy are compared with few other models and found as CFM is a better model with 0.01% in sensitivity and 0.03% increase in accuracy. The average MSE is calculated as 0.002595 and IEF as 4.89. Thus CFM is developed as a drusen enhancement model.

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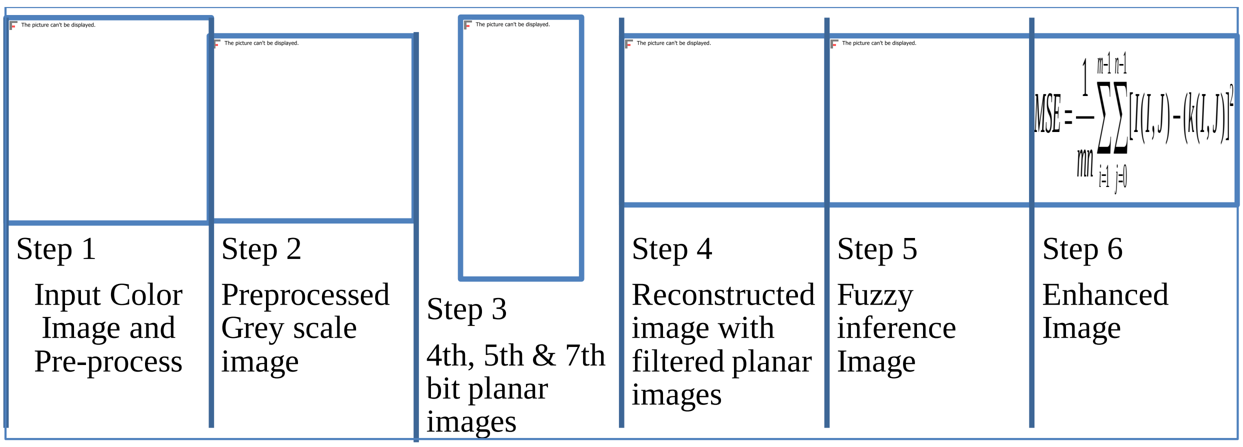

Figure 1. Process of Model Building

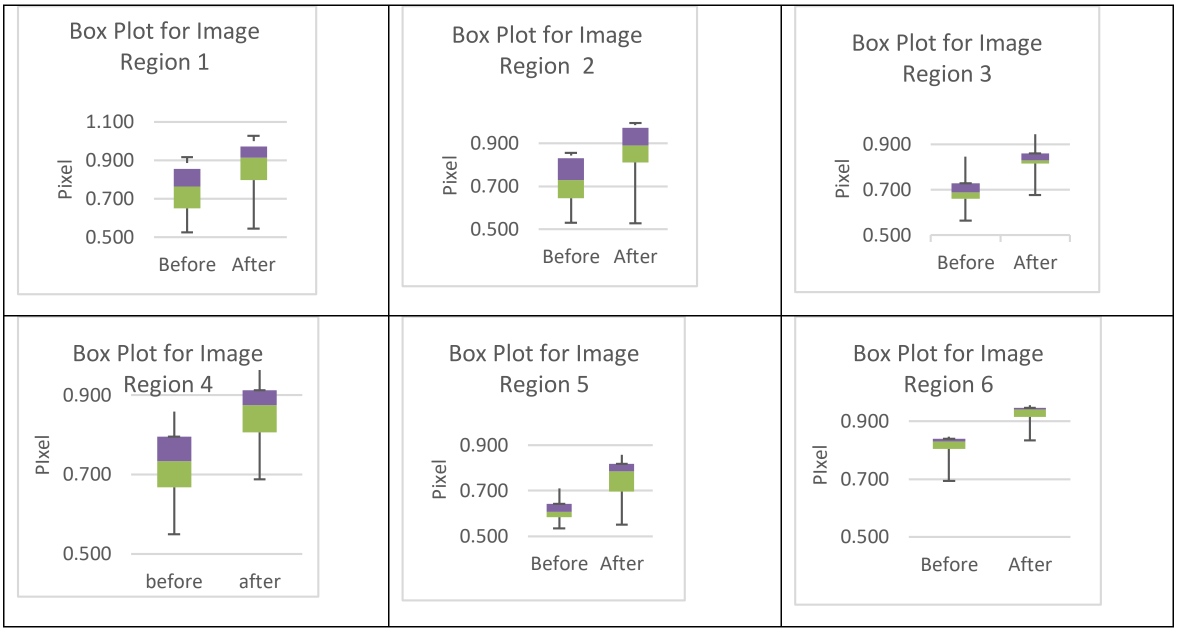

Figure 2: Box and Whisker plot before and after enhancement.

Table 1: Median differences before and after enhancement

Image Region #	Median difference
1	0.150
2	0.160
3	0.143
4	0.142
5	0.178
6	0.109
Average	0.147

Table 2. Performance Measures of various enhanced regions

Image Region #	Sensitivity	Specificity	Accuracy	Precision	F1-score
1	1.00	0.83	0.83	0.96	0.98
2	0.79	1.00	0.97	1.00	0.88
3	0.86	0.86	0.95	0.97	0.91
4	0.90	0.83	0.95	0.97	0.93
5	0.92	0.93	0.99	0.98	0.95
6	0.93	0.85	0.99	0.97	0.95
7	0.95	0.90	0.97	0.98	0.97
8	0.96	0.88	0.98	0.96	0.96
9	0.92	0.89	0.91	0.97	0.94
10	0.89	0.84	0.95	0.95	0.92
Average	**0.91**	**0.88**	**0.95**	**0.97**	**0.94**

Table 3. Performances Measures of various models

#	Method	Sensitivity	Specificity	Accuracy	Precision	F1-Score
1	Machine Learning Approach[6]	0.77	0.88	NA	NA	NA
2	Maximal region-based pixel intensity approach[7]	0.75	0.75	0.75	NA	NA
3	Learning Based LS-SVM Approach[8]	0.75	0.84	0.83	NA	NA
4	K Nearest Neighbour Classifier[9]	0.9	**0.92**	0.92	NA	NA
5	Classification using SVM[10]	0.9	0.87	NA	NA	NA
6	Kirsch Template based Filter Method[11]	0.87	0.75	0.79	NA	NA
7	Detecting AMD by extraction of blood vessels[12]	NA	NA	0.90	NA	NA
8	Fuzzy Based Approach – Proposed[4]	**0.91**	0.88	**0.95**	**0.97**	**0.94**

Table 4. Mean Squared Error and Image Enhancement Factor

Private Data				STARE Data			
#	MSE		IEF	#	MSE		IEF
	Before	After			Before	After	
1	0.0124	0.0039	3.2248	1	0.0108	0.0017	6.4054
2	0.0146	0.0033	4.3858	2	0.0113	0.0017	6.6608
3	0.0169	0.0028	5.9592	3	0.0109	0.0024	4.486
4	0.0108	0.0027	3.9812	4	0.0094	0.002	4.7825
5	0.0086	0.002	4.3413	5	0.0099	0.0052	1.9057
6	0.0103	0.0017	6.0401	6	0.0163	0.0021	7.588
7	0.0156	0.0031	5.0875	7	0.0144	0.0019	7.6962
8	0.0113	0.0018	6.2484	8	0.0105	0.0021	4.9444
9	0.0208	0.0053	3.9046	9	0.0088	0.0027	3.301
10	0.0095	0.0017	5.7286	10	0.0091	0.0018	5.1029
Avg.	0.01308	0.00283	4.89015	Avg.	0.01114	0.00236	5.28729

Table 5. Comparison of MSE

Method	MSE		
	Private Data	STARE Data	Average
Enhancement using Contrast, Luminosity adjustment, MSC[14]	0.048	Nil	Nil
Combinatorial Filter Model[4]	0. 00283	0. 002360	.002595