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Retinal Image Analysis for ROP Plus Diagnosis and Detection

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Abstract:
In this work an attempt is made to address the Retinopathy of prematurity (ROP) plus disease analysis and verification of the developed methods and algorithms in consultation with the ophthalmology expert. Few of the test cases were used in analysing the vessel width dilation and tortuosity of the retinal image features for setting and confirming the thresholds to classify the cases as normal and abnormal.

The adopted thresholds are testified for confirmation by running the algorithmic simulation for a set of selected test cases chosen from the study reported by other groups. The results of which showed the set threshold as good measures in predicting. Further to gauge the accuracy of the algorithm expert opinion were collected and compared with the results of algorithmic simulation for a selected test cases. The outcome of the approach showed the accuracy of the algorithm to be >75%.

Keywords*: DVW, OPBA, RI, ROP.*

I. Introduction

Retinopathy of prematurity is an eye disease typically diagnosed in NICU (Neonatal Intensive Care Unit) admitted prematurely-born infants that are treated with oxygen therapy. Oxygen toxicity and relative hypoxia are the probable causal factors of ROP and it is characterized by disorganized growth of retinal blood vessels. If it is not treated timely it may lead to scarring, retinal detachment and in advanced stages it may lead to permanent blindness [1, 3].

Current diagnostic methods involve human intervention, which has ample room for human errors due to microscopic features involved in the process. Development and application of computer algorithms can improvise the analysis part of the diagnostics with the increase in accuracy. In ophthalmology, Retinopathy of prematurity (ROP) is one such class of problem; where in retinal vascular analysis is essential and is typical. In this work an attempt is made to address the Retinopathy of prematurity (ROP) plus disease analysis with the development of methods and algorithms.

II. Review of Related works

Dongbo Zhang et al. [2, 8] presented a novel optic disc detection method based on the retinal vessel characteristics. Local vessel density, compactness, and uniformity characters of the vessels are used to identify the optic disc coordinates. Further the efficiency of the method was improvised by divide and conquers approach by turning the 2D search problem in to two 1D search problems.

Heneghan et al.[3] reported a morphological filtering and Gaussian approximation based technique for the vascular skeleton segmentation and characterization of the retinal vessels.

Heneghan et al. [3] extracted the binarized vascular structure by applying the linear and morphological filtering on the fundus images. Followed by this, the vessel width was computed by using an extending rotating reference line placed at every pixel of the selected segment, shortest distance to the boundary was taken as the vessel width. A similar method was discussed by G. Stabingis et.al. [4].

Vinekar et al. [5] have applied average thresholding technique by considering the vessel length and maximum vessel width for the normal case and

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minimal vessel width for the abnormal or PLUS case. Irrespective of the method being used or applied, threshold selection is a debatable aspect that involves argument about data sufficiency.

JW Park et al. [7] conducted study to analyze the correlation between the infant's gestational age/ birth weight and their optic disc parameters. The study discloses that there is no solid correlation between the optic disc parameters with gestational age / birth weight in infants. The statistics of American academy of paediatrics helps classify and screening of ROP cases [6].

Rashmi et al. [9] proposed a robust metric based curvature computation using chain code algorithm, which gives quantitative analysis of retinal vessel tortuosity. The basic equation for curvature calculation referred is eq. no 2.1, for tortuosity evaluation selecting a region varied from two to ten pixels before curvature calculation. Small changes in value of k (i.e k=1) may give error in the slope calculations to overcome this k should be greater than one. The window size of 17 pixels is considered for better results.

III. Major Vessel Identification and Boundary Extraction

Computation of vessel width and tortuosity requires vessel extraction. The pre-processed binarized image containing vascular network information, $V_N(x,y)$ matrix with the binarized pixel values is ready for vessel extraction [11-14]. Analysis of the vascular network $V_N(x,y)$ shows that the vessels are connected pixel lines or regions with pixel value of 1 and having well defined Cartesian co-ordinate2-D positional information. The background pixels that are not part of any vessels and are set to zero value with image contrast enhancement and binarization.

To extract the individual vessels, $\mathbf{V}$ from the network, $V_N(x,y)$ multi stage connectivity and regional property identification methods are employed repeatedly followed by correlation analysis and radon transform [12,20], the cuts and sprouts are treated as part of vessels.

$$\mathbf{V} = \{V_1, V_2, V_3 \ldots V_n\} \quad (1)$$

$$\mathrm{BI}(x,y,\theta_n) = \sum_{m=1}^{N} \cdot \sum_{n=1}^{N} f_{vn}(x,y,\theta_n) + \quad (2)$$

$$\mathrm{ODx}=\{-X2, X2\} \quad , y=\{-y2, y2\}$$

$$f_{vn}(x,y,\theta_n) = \quad (3)$$

$$(1 + \sum_{m=1}^{vn} x_m + x_m^2 + ..) a_m \cos\theta_n \theta_n = n * \theta$$

Equation (3) implies that individual vessel boundary can be extracted by masking the image, $\mathrm{BI}(x,y,\theta_n)$ (equation 2) with angular delta function $\delta(x - x, \delta(\theta - \theta n)$ as

$$f_{vn}(x,y,\theta_n) = \sum_{x=-\frac{X}{2}}^{\frac{X}{2}} \mathrm{BI}(x,y,\theta_n)\, \delta(x' - x)\delta(\theta - \theta_n) \quad (4)$$

The dilation symptoms are most prevalently associated with the longer vessels due to the physiological process and the chances of dilation being diagnosed with short length vessels are very meagre [17]. This fact makes the selective vessel processing a natural choice [18, 19]. The branching points in vascular network are treated as part of the vessel strings, vessels thus identified are subject to the pixel wise length analysis where in a longest vessel is selected and 75% of its value is taken as threshold for selecting the measurable vessels as major vessels [3, 10, 11]. The vessel, V_i with length (in terms of number of pixels) greater than the set threshold are classified as major vessels, $\mathbf{V_M}$ (equation 5) and considered for further processing. The selecting of the major vessels and segmentation are based on previous work done [21, 22].

$$\mathbf{V_M} = \{V_{M1}, V_{M2}, V_{M3} \ldots V_{Mn}\}$$
$$V_{Mi} \in \mathbf{V_M} \in \mathbf{V_N}(x,y) \quad (5)$$

III a. Results of Tortuosity Computation

The tortuosity index is computed by taking average of segment curvature of every major vessel and is represented by Zi (Tortuosity index).

$$Z_i = \frac{1}{N} \sum_{i=1}^{N} Seg_c(i) \quad (6)$$

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The algorithm is applied iteratively every fundus retinal images (from selected data set i.e Drive, Fire and local data set). The computational output for the plus and without plus fundus retinal images are shown in Table 2.The tortuosity index and vessel level tortuosity levels are calculated based on the previous work [22].

III b. Results and Discussion of vessel width computation

a)

b)

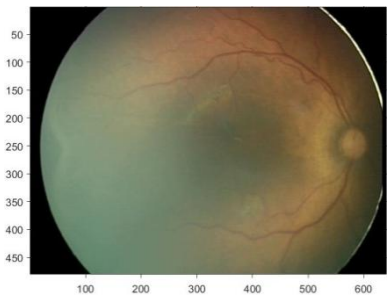

Figure 1: M-32 and M-13 Retinal images a) M-32 normal. b) M-13 abnormal.

The pre-processed retinal images are operated by the major vessel extraction function to identify and extract the major vessels. The major vessels thus identified are processed further to extract the boundaries of the vessels, these vessels with identified boundaries are individually taken through the width computation algorithms OPBA. Figure 1 (a) and (b) shows the two retinal images of different cases, selected from local data base as based on discussions with ophthalmologists. The vessel width will be computed based on equation 7[21].

$$w_{V_{mi}} = \frac{\sum_{j=1}^{M_{V_{mi}}} \tilde{w}_{V_{mi},S_j}}{N_{V_{mi}}} \qquad (7)$$

This calculation results in width index which is independent of the camera and its resolution used in capturing the respective retinal image. The obtained value of the index can be converted into length in units by multiplying the index with the resolution of the camera and K, computed as Width in µm = (Normalized RI size /Actual RI size) x Actual resolution in µm.

IV. Results and Discussions

In order to classify the RI into ROP Plus or normal, the results of tortuosity and vessel width computation needs to be processed comparatively with respect to the expert and standard markings or threshold values. Arriving at a fixed threshold value is quite challenging as it involves finding empirical value based on a number of case studies made for the normal and PLUS diseases. Vinekar et al. [4] have applied average thresholding technique by considering the vessel length and maximum vessel width for the normal case and minimal vessel width for the abnormal or PLUS case. Irrespective of the method being used or applied, threshold selection is a debatable aspect that involves argument about data sufficiency. In current work dual thresholding is applied by setting separate thresholds for the vessel width and vessel tortuosity.

Table 1 Threshold level for Plus

	Vessel Width index	**Vascular Tortuosity index**
No Plus	≤ 1.5	≤ 3.1
With Plus	≥ 1.6	≥ 3.2

To arrive at this dual empirical threshold values, observations reported by Heneghan, et al.[2] and Vinekar, et al.[4] are used, as these reports are based on considerable cases. Table 1 shows the empirical threshold values that applied in the case studies reported in Table 2.

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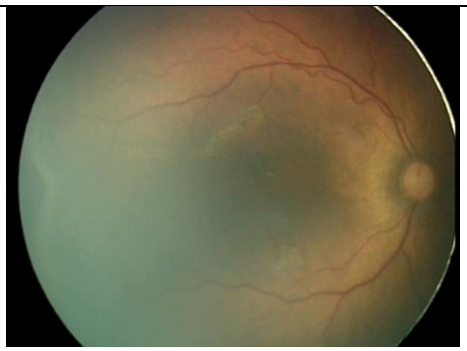
Table 2 Comparative analysis with Local data set test cases (M32 and M13).

	RI	Vessel Width	Vascular Tortuosity	Algorithm prediction	Expert Opinion
M32		1.49	3.1	N	N
M13		2.89	5.09	AN	AN

Comparison of obtained results with Ophthalmology expert: Information listed in the following Table 3 is based on the algorithm prediction and the expert opinion recorded. A comparison table of results obtained from the algorithm with expert opinion is noted in Table 4.

Table 3 Algorithm validation with respect to the expert opinion.

Sl No	RI		Algorithm prediction	Expert Openion-1	Expert Openion-2
1.	P_37	AN	AN	AN	
2.	S63_1	AN	AN	N	
3.	M32	N	NOC	AN	
4.	M14	AN	AN	AN	
5.	M13	AN	AN	AN	
6.	M1	AN	AN	AN	
7.	P29_1	AN	AN	AN	
8.	03-test	AN	AN	AN	
9.	11_test	N	N	AN	
10.	Im0236	N	AN	N	
11.	Im0237	AN	AN	N	
12.	05_dr	N	N	N	

NOTE: N- Normal (No Plus), AN-Abnormal (Plus), NOC- No comment

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Outcome:
Number of cases considered: 12
Plus cases identified in confirmation:

Table 4 Algorithm prediction comparison with respect to the expert opinion.

Comparision	**Found Matching/True**	**Difference/False**
By algorithm prediction with By expert-1 opinion:	10	1
By algorithm prediction with expert-2 opinion:	9	3

* Note: Expert-1 commented on only 11 images.

V. Conclusion

The work presented in this paper an analysis of the algorithm and scholastic reports for different test cases of the standard data set, scholastic reports and local data set. Few of the test cases were used in analysing the vessel width and tortuosity of the retinal image features for setting and confirming the thresholds to classify the cases as normal and abnormal.

The adopted thresholds are testified for confirmation by running the algorithmic simulation for a set of selected test cases chosen from the study reported by other groups. The results of which showed the set threshold as good measures in predicting. Further to gauge the accuracy of the algorithm expert opinion were collected and compared with the results of algorithmic simulation for a selected test cases. The outcome of the approach showed the accuracy of the algorithm to be >75%. The results reported here are based on available data sets with good combination of normal and abnormal cases, with limited number of test possibilities due to the data limitation.

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