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Retinal Vessel Analysis for Early Detection of Retinopathy of Prematurity Using Image Processing

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Abstract. Retinopathy of Prematurity is an eye disease that occurs in premature babies[1] where the major risk factors include birth before thirty-four weeks of gestation, low birth weight (less than 2 kg), and high exposure to oxygen. Early detection of these abnormalities can reduce the rate of blindness worldwide. The main objective of this work is to develop an algorithm using image processing techniques to analyse important retinal blood vessel features such as vessel width and tortuosity for the detection of Retinopathy of Prematurity (ROP). The process begins by converting retinal fundus images into grayscale and resizing them to a fixed size so that all images can be processed in a consistent manner. After that, a Gaussian filter is applied to reduce noise, and adaptive histogram equalization is used to improve the image contrast and make the blood vessels more visible. Once the pre-processing stage is completed, the optic disc is removed because it can affect the vessel analysis. The blood vessels are then enhanced using a bottom-hat transform, and global thresholding is applied to obtain a binary image of the vessel network. Small unwanted branches and noise are removed so that only the major vessel structures remain. Skeletonization and geodesic path analysis are then carried out to segment the vessels and extract the required features for further analysis. The vessel width is estimated by measuring the distance between each vessel centreline pixel and the vessel boundary using a distance transform technique. Tortuosity is calculated by comparing the actual length of a vessel with the straight-line distance between its starting and ending points.it just display the values of vessel width and tortuosity it does not directly classify whether ROP is present or not. Based on this, it assists doctors in making quicker decisions and may help reduce the chances of vision-related complications in premature infants through early detection.

Keywords: *vascular network; retinal vessel analysis; ROP; vessel tortuosity; vessel width*

1. INTRODUCTION

Retinopathy of Prematurity (ROP) is a retinal vascular disease that affects premature infants and can lead to permanent vision loss if not detected at an early stage. Clinical assessment of ROP mainly depends on examining retinal blood vessel characteristics, particularly vessel width and tortuosity, which become increasingly abnormal as the disease progresses. However, manual measurement [4]of these features is time-consuming and depends on the experience of the ophthalmologist, making consistent evaluation difficult.

This work presents a MATLAB-based approach for automated extraction and analysis of major retinal blood vessels from fundus images. The proposed method enhances retinal vessels using image preprocessing and morphological operations, removes the optic disc and unwanted artifacts, and extracts the major vessels for further

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analysis. Skeletonization and geodesic path analysis are then used to segment each vessel, while vessel width is estimated using a distance transform and tortuosity is computed from the ratio of vessel path length to the straight-line distance between its endpoints. By providing objective measurements of these vascular features, the proposed approach offers a reliable tool for quantitative retinal vessel analysis that can support computer-aided ROP assessment. Fig. 1. Sample retinal fundus image showing retinal blood vessels and optic disc used for vessel width and tortuosity analysis. Fig. 2. Retinal fundus image used for preprocessing and retinal vessel extraction in the proposed methodology.

Fig. 1. Retinal fundus image used for vessel width and tortuosity analysis

Fig. 2. Retinal fundus image used for preprocessing and retinal vessel extraction

Several researchers have proposed automated methods for analyzing retinal blood vessels.[8][10] Previous studies have used image enhancement, vessel segmentation, curvature analysis, and centerline extraction to quantify retinal vascular characteristics. Hart et al. introduced an automated approach for measuring retinal vessel tortuosity using curvature-based features, vessel path length, and straight-line distance, demonstrating that quantitative measurements can support ophthalmologists in retinal disease assessment. Other researchers have developed algorithms that estimate vessel width and tortuosity using preprocessing, vessel extraction, and threshold-based classification[2][4][5] for detecting Plus disease. Curvature-based[6] methods have also been investigated, where retinal vessels are segmented into smaller sections and their average curvature is used as an indicator of abnormal tortuosity. These studies have shown that retinal vessel analysis can improve the objectivity of ROP screening[7][13].
However, most existing methods primarily focus on feature measurement or disease classification, [11] while limited attention has been given to obtaining reliable measurements from only the major retinal vessels after removing unwanted branches and image artifacts. In addition, accurate segment-wise analysis of vessel width and tortuosity remains challenging because branching vessels and imaging artifacts can influence the measured values.

2. METHODOLOGY

A. Input Retinal Image

The proposed system begins with an RGB retinal fundus image obtained from the FIRE dataset. To maintain uniformity during processing, each image is resized to 1024 × 1024 pixels. Standardizing the image size ensures consistent performance of image processing algorithms and improves the accuracy of vessel extraction and feature measurement.

B. Image Preprocessing

The green channel of the RGB image is selected because it provides better contrast between blood vessels and the retinal background than the other color channels. A Gaussian filter is applied to reduce image noise, followed by Contrast Limited Adaptive Histogram Equalization (CLAHE) to enhance local contrast. Finally, a median filter removes impulse noise while preserving vessel boundaries, producing a cleaner image for segmentation[3].

C. Optic Disc Removal

The optic disc appears as the brightest region in the retinal image and may be incorrectly detected as blood vessels during segmentation. To avoid this, the optic disc is manually outlined using a polygon selection tool in MATLAB, and a binary mask is created. The masked region is excluded from further processing, improving the accuracy of vessel extraction[9][12].

D. Image Enhancement

A morphological bottom-hat transformation is applied to enhance the visibility of retinal blood vessels by suppressing uneven background illumination. This operation increases the contrast between vessel structures and the surrounding retinal tissue, making the major vessels more distinguishable for the subsequent segmentation process. Fig 3. Proposed methodology for retinal vessel extraction, segmentation, width measurement, and tortuosity analysis in ROP retinal images.

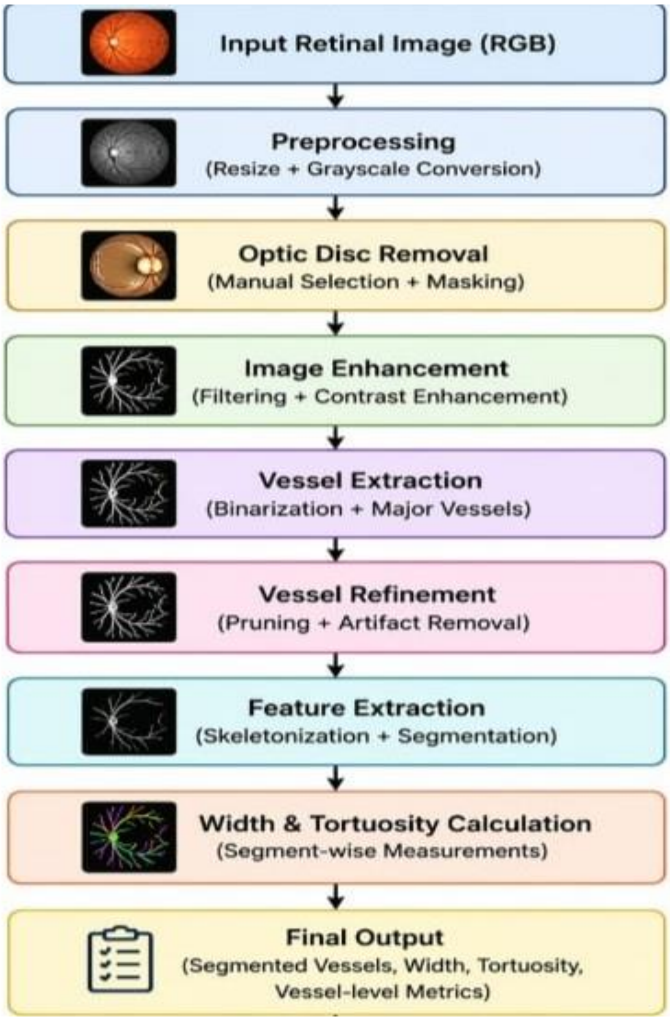

Fig. 3. Workflow of retinal vessel width and tortuosity analysis

E. Vessel Extraction

The enhanced image is converted into a binary image using Otsu's thresholding method. Small noisy regions are removed using area-based filtering, and the optic disc mask is applied to eliminate unwanted pixels. Connected component analysis is then performed, and the four largest vessel components are selected as the major retinal vessels for further analysis.

F. Vessel Refinement

The extracted vessels are refined using morphological opening to remove small branches while preserving the original width of the major vessels. Additional area filtering removes disconnected components, and a border mask eliminates artifacts near the image boundary. This produces a cleaner vessel map suitable for feature extraction.

G. Feature Extraction

Each refined vessel is skeletonized to obtain a one-pixel-wide centerline while preserving its shape. Small side branches are removed through iterative pruning to retain the longest vessel path. Geodesic distance is then used to divide each vessel into 20 equal segments, enabling detailed segment-wise analysis of retinal vessel characteristics.

H. Vessel Width and Tortuosity Calculation

The width of each vessel segment is calculated using the Euclidean distance transform by measuring the distance from the vessel centerline to its boundary. Tortuosity[10] is computed as the ratio of the actual vessel path length to the straight-line distance between the segment endpoints. Average width and tortuosity values are then obtained for each vessel.

I. Final Output

The final output consists of color-coded segmented retinal vessels along with quantitative measurements of vessel width and tortuosity for each segment. Vessel-level average values are also reported, providing objective retinal vascular features that can support computer-aided analysis of Retinopathy of Prematurity (ROP).

3. RESULTS AND DISCUSSIONS

The study on ROP plus detection using image processing techniques can play an important role in the early detection of ROP plus disease. Plus disease is mainly identified through abnormal widening and twisting of retinal blood vessels. By applying preprocessing methods such as noise removal, contrast enhancement and vessel segmentation, the retinal images become clearer and easier to analyze. After extracting this vessel features , then the proposed system can distinguish normal retinal patterns from those associated with plus disease.

These results are consistent with earlier research, where vessel tortuosity and dilation are considered as the most significant indicators of plus disease. This makes computer aided diagnosis useful in hospitals where specialist ophthalmologists may not always be available. An automated detection system can be used as a tool in neonatal hospitals and screening centers. Early identification of severe ROP can help ensure timely medical intervention and reduce the risk of permanent vision loss in premature infants.

Overall, the study confirms that the image processing methods provide a reliable and efficient approach for detecting ROP plus disease. It has the potential to improve early diagnosis and help prevent blindness in premature infants through timely treatment. Observations were found in present research, where vessel analysis helped improve disease detection performance. The findings highlighted the need for timely diagnosis and continuous monitoring in premature infants [7-8]. The research highlights the importance of early diagnosis and continuous screening. The findings suggest that identifying important retinal structures increases the precision of automated systems. The automated vessel width measurement further supports the significance of retinal vessel analysis [11-13].

Image Preprocessing: The retinal RGB image is first resized to a standard resolution and converted to the green channel for further processing. Figure 4 shows the original retinal fundus image used as the input to the proposed system. CLAHE Enhancement: To improve the visibility of retinal blood vessels, Contrast Limited Adaptive Histogram Equalization (CLAHE) is applied after Gaussian filtering. As shown in Fig. 5, the enhanced image exhibits improved local contrast, making the vessel structures more distinguishable from the background. Vessel Extraction: The enhanced image is converted into a binary vessel map using Otsu's thresholding method. Small noisy regions are removed through area filtering to retain only the vessel structures. The resulting binary vessel image is shown in Fig. 6. Major Vessel Extraction: Connected component analysis is performed on the binary image, and the four largest connected vessel components are selected as the major retinal vessels. The extracted major vessels are illustrated in Fig. 7. Vessel Segmentation:Each major vessel is skeletonized and divided into twenty equal segments using geodesic distance. The segmented vessels obtained after feature extraction are shown in Fig. 8.

Fig. 4. Original retinal fundus image

Fig. 5. CLAHE enhanced retinal image

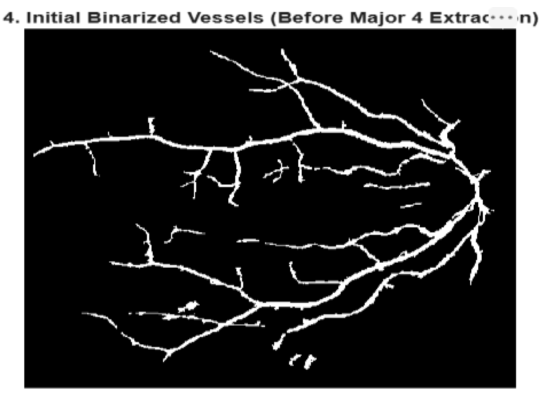

Fig. 6. Binary vessel segmentation

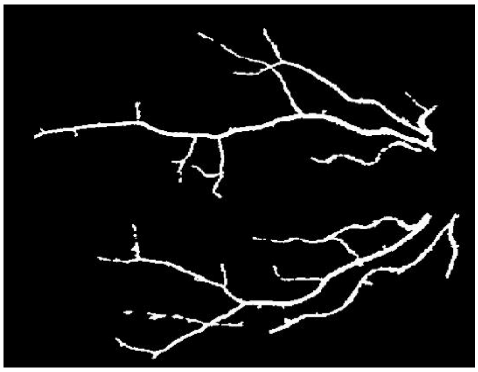

Fig. 7. Extracted Major retinal vessels

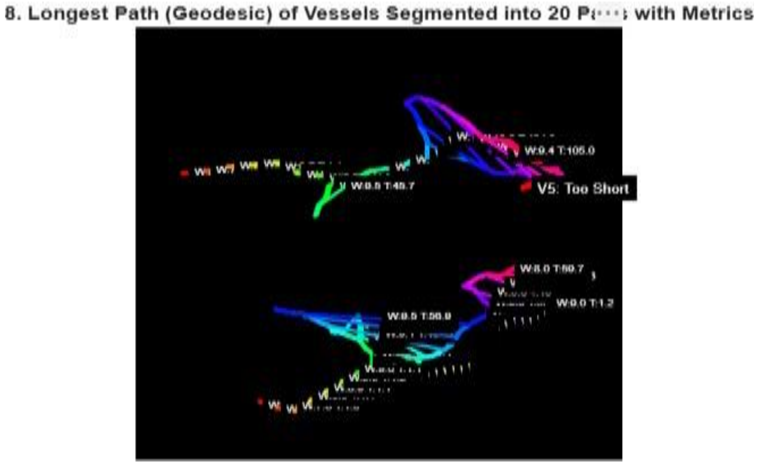

Fig. 8. Segmented major retinal vessels for width and tortuosity analysis.

Table 1 presents the retinal fundus images along with the quantitative measurements obtained using the proposed method. For each image average vessel width, and vessel tortuosity values are reported, providing an objective assessment of retinal vascular characteristics.

Table 1. Retinal image analysis results

Sr.	Test Images	Findings
1.		• Vessel 1 Average Width: 9.81 pixels Average Tortuosity (Length-to-Chord):12.68 • Vessel 2 Average Width:8.96 pixels Average Tortuosity (Length-to-Chord):6.99 • Vessel 3 Average Width: 8.77 pixels Average Tortuosity (Length-to-Chord):1.41
2.		• Vessel 1: Average Width: 8.17 pixels Average Tortuosity (Length-to-Chord):1.09 • Vessel 2: Average Width: 9.94 pixels, Average Tortuosity (Length-to-Chord):2.63 • Vessel 3: Average Width: 9.99 pixels, Average Tortuosity (Length-to-Chord):54.69 • Vessel 4: Average Width: 11.70 pixels, Average Tortuosity (Length-to-Chord):41.29

3.		• Vessel 1: Average Width: 10.11 pixels, Average Tortuosity (Length-to-Chord):1.08 • Vessel 2: Average Width: 10.11 pixels, Average Tortuosity (Length-to Chord):4.72 • Vessel 3: Average Width: 0.00 pixels, Average Tortuosity (Length-to-Chord):0.00

The proposed method was evaluated using retinal fundus images from the FIRE dataset. The algorithm was tested on 30 retinal images to verify the extraction of major retinal vessels and the computation of vessel width and tortuosity. Since the proposed method performs quantitative feature extraction rather than disease classification, conventional performance measures such as classification accuracy are not applicable. The results demonstrate that the algorithm successfully extracts the major vessels and provides consistent width and tortuosity measurements for retinal vascular analysis.

One limitation of the proposed method is that optic disc removal is performed manually using polygon-based masking. Although this approach improves vessel extraction accuracy, it requires user intervention and reduces the level of automation. Consequently, the processing time depends on the operator, making the method less suitable for large-scale screening applications.

4. CONCLUSION

The proposed Retinopathy of Prematurity (ROP) detection system gives an effective approach for analyzing retinal fundus images using image processing techniques. The implemented methodology performs image preprocessing, optic disc removal, vessel enhancement, segmentation, pruning, and extraction of major blood vessels to obtain clear vascular structures for analysis. The algorithm further evaluates important vascular characteristics such as vessel width and tortuosity[14][5] , which are major indicators in identifying abnormal retinal development associated with ROP. Segment-wise analysis improves the precision of measurement and enables better visualization of vascular abnormalities. The use of skeletonization and longest path extraction also helps in maintaining vessel continuity and improving the reliability of the calculated metrics. Overall, the developed system provides a structured and automated framework for retinal vessel analysis that can support early screening of Retinopathy of Prematurity. Early identification of abnormal vessel behavior can assist ophthalmologists in timely diagnosis and treatment, thereby helping to reduce the risk of vision impairment and blindness in premature infants. Future work will focus on replacing the manual optic disc removal step with an automatic optic disc detection algorithm based on image segmentation or deep learning techniques.

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