Detection of plus disease in retinopathy of prematurity using automatic vessel tortuosity measurements

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Purpose

Objective

To automatically detect the presence of Plus disease in retinal images of neonates by quantifying the level of tortuosity in the retinal vasculature.

Background

Retinopathy of prematurity (ROP) is a vasoproliferative retinal disorder affecting low birth weight infants and the leading cause of avoidable blindness in children.

Management of this neonatal retinal disorder depends largely on timely screening and intervention performed by ophthalmologists.

Plus disease is defined by increased venous dilation and arterial tortuosity of the posterior retinal vessels. These signs indicate that the disease is active and that it can progress to more advanced stages.

Methods

The method consists of three steps: image enhancement, retinal vessel segmentation, and vessel tortuosity measurements.

- Image enhancement
  - The method is based on the subtraction of a Gaussian blurred version of the image to reduce noise, followed by the application of a non-linear diffusion filter to preserve edges.
  - A contrast limited adaptive histogram equalization (CLAHE) technique is used to enhance the contrast of the image.
  - Anisotropic diffusion is applied to further reduce noise while preserving edges.

- Vessel Segmentation
  - The method uses a multiscale vessel enhancement technique to detect the presence of vessels.
  - The optimum threshold for vessel segmentation is found by calculating the vessel density for a fixed threshold value.
  - The threshold is then varied based on this density.
  - Finally, the blood vessels are skeletonized, crossing and branching points are removed, and tortuosity is calculated.

- Tortuosity
  - The tortuosity is calculated using four different methods:
    1. Calculation of the proportion of the arc length (L) to the length of the segment (L) in 30 pixel increments.
    2. Calculation of the total curvature using numerical differentiation:
       \[
       \tau = \frac{\sum_{i=1}^{n} \frac{x_{i+1} - x_{i}}{L_{i}^2} \frac{y_{i+1} - y_{i}}{L_{i}^2}} {\sum_{i=1}^{n} \frac{1}{L_{i}^2}}
       \]
    3. Combination of 1 and 2 to improve the accuracy of the method.
    4. The top 3 tortuosity values are used as thresholds to identify potential plus disease.

Results

Dataset

- 66 imaging sessions of preterm babies <31 weeks gestational age and <1500g birth weight.
- Clinical ground truth was determined by a retina specialist.
- 25 imaging sessions had plus disease and 61 did not have plus disease.

We tested the four different methods for the classification of plus disease.

Table 1. The results of the tortuosity measurements for the plus disease cases.

<table>
<thead>
<tr>
<th>Method</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method 1</td>
<td>0.63</td>
</tr>
<tr>
<td>Method 2</td>
<td>0.66</td>
</tr>
<tr>
<td>Method 3</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Table 1. Area under the curve (AUC) for the 4 tortuosity methods.

Graphical User Interface

- The method to detect the presence of plus disease is part of a graphical user interface (GUI) for grading ROP images.
- This GUI’s objective is to help with the assessment of metrics most commonly associated with ROP.
- The metrics include vesel width quantification, delineation of zone, image montage, artery vein classification, and demarcation line finding.

Tools for editing results are also implemented in a graphical user interface that can be seen in Figure 3. These modules have automatic and semiautomatic methods to give a tradeoff between speed and accuracy.

Conclusions

- We demonstrated that our automatic approach can detect cases of plus disease with high sensitivity and better agreement with the clinical ground truth than the reader, making the system ideal as a screening tool.

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