Use of Spatial Filters for Improved Detection of Glaucomatous Visual Field Progression

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Purpose

• Accurate detection of VF progression remains challenging due to the inherent test-retest variability in VF measurements.
• This research investigates the use of spatial correlation filters to reduce the influence of test variability on the detection of VF progression.
• A novel simulation method for longitudinal VF measurements was proposed to support the performance evaluation.

Methods: Simulation of Longitudinal VF

• Simulation provides the “ground-truth” status of VF progression and thus facilitates quantitative performance evaluations.
• 500 stable and 500 progressing VF sequences (15 tests/sequence, 6 months apart) were generated with controlled progression rates based on 500 real VF tests from 500 glaucoma patients (Figure 1).
• The statistical properties and baseline defect patterns of real VF tests were used to ensure the simulated data were similar to real fields.

Figure 1. A simulated VF sequence with moderate arcuate baseline defects and the mean deviation deteriorated at 0.5 dB/year.

Methods: VF Spatial Correlation Filter

• Glaucomatous damages typically manifest in localized areas at the optic disc.
• VF measurements at different locations are correlated by:
  1. Anatomical distance: the angular distance that the retinal nerve fiber layer bundles supporting two VF points enter the optic disc, in Garway-Heath [1]. VF test points with shorter anatomical distances exhibit higher correlations.
  2. Spatial distance: the Euclidean angular distance between points on the VF testing grid.
• VF spatial correlation model [2]:
  \[
  \text{corr}_{pq} = \begin{cases} 
  \exp(-\frac{1}{2} \frac{\text{dis}_{pq}^2}{\delta_1^2} + \frac{\text{dis}_{pq}^2}{\delta_2^2}) & \text{If } p \text{ and } q \text{ are in the same hemifield} \\
  0 & \text{Otherwise}
  \end{cases}
  \]
  where \(\text{corr}_{pq}\) is the correlation between VF test points \(p\) and \(q\), \(\text{dis}_{pq}\) and \(\text{dis}_{pq}\) represent the difference of Garway-Heath angles and the Euclidean distance between \(p\) and \(q\), and \(\delta_1 = 6\), \(\delta_2 = 14\); see [2] for details.
• The filtered sensitivity at each test point equals to the weighted average of the sensitivities at all other points.
• The weights are determined by the correlation coefficients.

Results

• Time to detect 80% of progressing eyes with 95% specificity and the mean MD progression rate at 0.5 dB/year (unit: years)

<table>
<thead>
<tr>
<th>Method</th>
<th>Time to detect w/o filter (mean ± SD)</th>
<th>Time to detect w/ filter (mean ± SD)</th>
<th>T-test p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>4.10 ± 0.26</td>
<td>4.05 ± 0.22</td>
<td>0.579</td>
</tr>
<tr>
<td>Regional</td>
<td>4.05 ± 0.15</td>
<td>3.61 ± 0.18</td>
<td>0.001</td>
</tr>
<tr>
<td>Pointwise</td>
<td>3.90 ± 0.22</td>
<td>3.00 ± 0.21</td>
<td>0.001</td>
</tr>
</tbody>
</table>

• Detection agreements (Fleiss’s kappa) between three trend-based methods with the mean MD progression rate at 0.5 dB/year

<table>
<thead>
<tr>
<th>Year from baseline</th>
<th>Detection agreements w/o spatial filter (mean ± SD)</th>
<th>Detection agreements w/ spatial filter (mean ± SD)</th>
<th>T-test p-values</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.37 ± 0.03</td>
<td>0.55 ± 0.02</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>0.65 ± 0.03</td>
<td>0.73 ± 0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>5</td>
<td>0.80 ± 0.01</td>
<td>0.85 ± 0.01</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Interpretation of agreement: Poor: \(k < 0.2\), Fair: \(0.21 < k \leq 0.4\), Moderate: \(0.41 < k \leq 0.6\), Good: \(0.61 < k \leq 0.8\), Almost perfect: \(0.81 \leq k \leq 1.0\)

Conclusions

• The spatial filter that uses anatomical and spatial distances of VF test points improves the time to detect 80% of VF progression for pointwise and regional trends analysis, whereas the time-to-detect for the global trend method remained the same.
• The VF spatial filter can improve the detection agreements between three trend-based methods at different follow-up time points, hence can be used as a validation tool to verify the clinical VF progression analysis results.

Figure 2. A simulated VF sequence with MD deteriorated at 0.3 dB/year.

The spatial filter can smooth localized noise while not affecting the MD values.