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

Yan Li[1], Runjie Bill Shi[2, 3], Willy Wong[1, 3], Yvonne Buys[4], Graham Trope[4], Moshe Eizenman[4]

1. Department of Electrical & Computer Engineering; 2. Temerty Faculty of Medicine; 3. Institute of Biomedical Engineering; 4. Department of Ophthalmology & Vision Sciences
University of Toronto, Toronto, Ontario, Canada

The Edward S. Rogers Sr. Department of Electrical & Computer Engineering
UNIVERSITY OF TORONTO

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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.

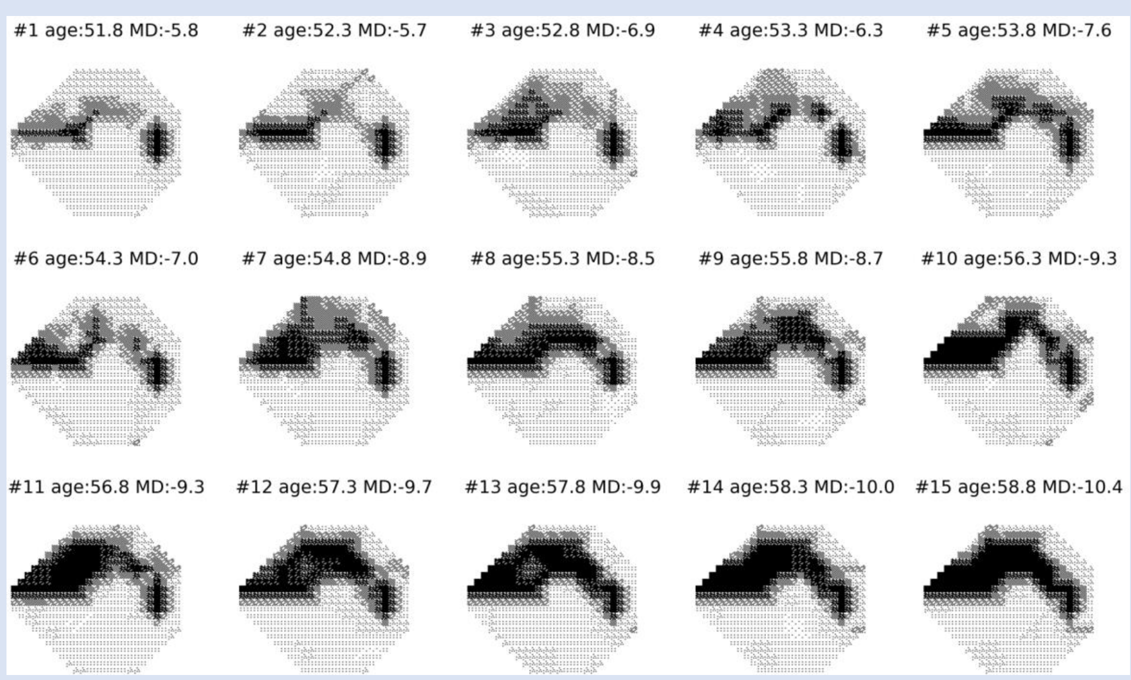


Figure 1. A simulated VF sequence with moderate arcuate baseline defects and the mean deviation deteriorated at -0.5 dB/year

Methods: Evaluation of VF Spatial Filter

- Trend-based VF progression analysis: global, pointwise, and regional trends.
- Tune the criteria of VF progression to match the detection specificity of three methods at 95% using the simulated stable VF sequences.
- Compare the time to detect 80% of the progressing eyes with and without using the spatial filter.
- Compare the detection agreements between three trend-based progression analysis methods with and without using the spatial filter.

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 angle [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]:
- $$corr_{pq} = \begin{cases} \exp\left(-\frac{1}{2}\left(\frac{dist_{pq}^2}{\delta_d^2} + \frac{\angle_{pq}^2}{\delta_\angle^2}\right)\right) & \text{If p and q are in the same hemifield} \\ 0 & \text{Otherwise} \end{cases}$$

  where $corr_{pq}$ is the correlation between VF test points p and q, $\angle_{pq}$ and $\boldsymbol{dist_{pq}}$ represent the difference of Garway-Heath angles and the Euclidean distance between p and q, and $\delta_d = 6$, $\delta_\angle = 14$, 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.

[1] Garway-Heath, David F., et al. "Mapping the visual field to the optic disc in normal tension glaucoma eyes."
[2] Zhu, Haogang, et al. "Detecting changes in retinal function: analysis with non-stationary Weibull error regression and spatial enhancement (ANSWERS)."

Results

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

Methods	Time to detect w/o filter: (mean ± SD)	Time to detect w/ filter: (mean ± SD)	T-test p-value
Global	4.10 ± 0.26	4.05 ± 0.22	0.570
Regional	4.05 ± 0.15	**3.61 ± 0.18**	$p < 0.001$
Pointwise	3.90 ± 0.22	**3.00 ± 0.21**	$p < 0.001$

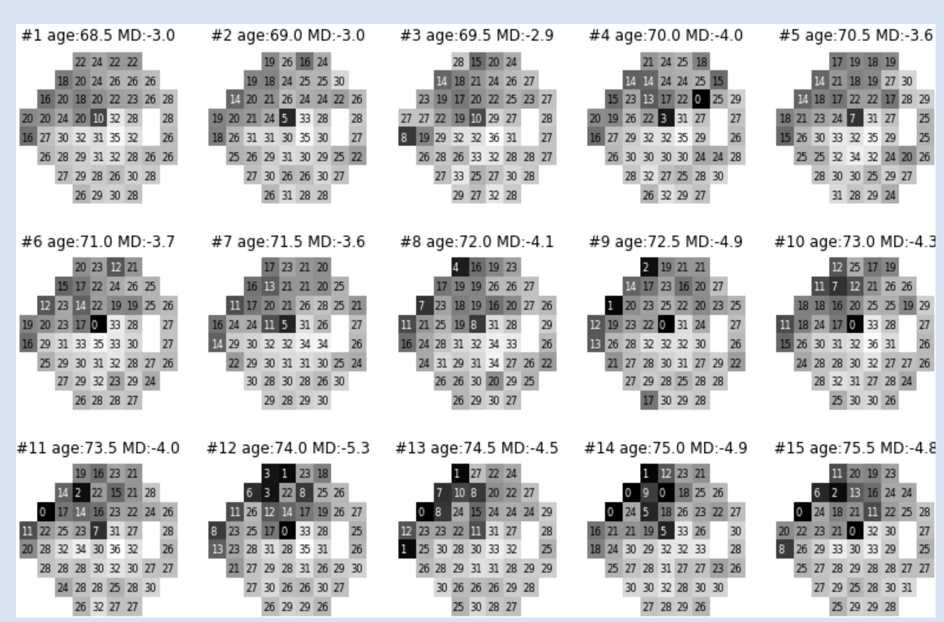
- Detection agreements (Fleiss's kappa) between three trend-based methods with the mean MD progression rate at -0.5 dB/year

Year from baseline	Detection agreements without spatial filter (mean ± SD)	Detection agreements with spatial filter (mean ± SD)	T-test p-values
2	0.37 ± 0.03	**0.55 ± 0.02**	$p < 0.001$
3	0.65 ± 0.03	**0.73 ± 0.01**	$p < 0.001$
5	0.80 ± 0.01	**0.85 ± 0.01**	$p < 0.001$

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

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.



A simulated progressing VF sequence with MD deteriorated at -0.3 dB/year

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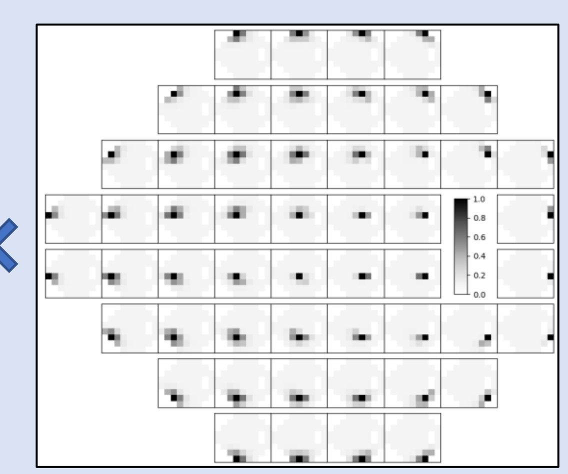

VF correlation matrix: each cell illustrates correlation coefficients for the current location, the darker color means the stronger correlation

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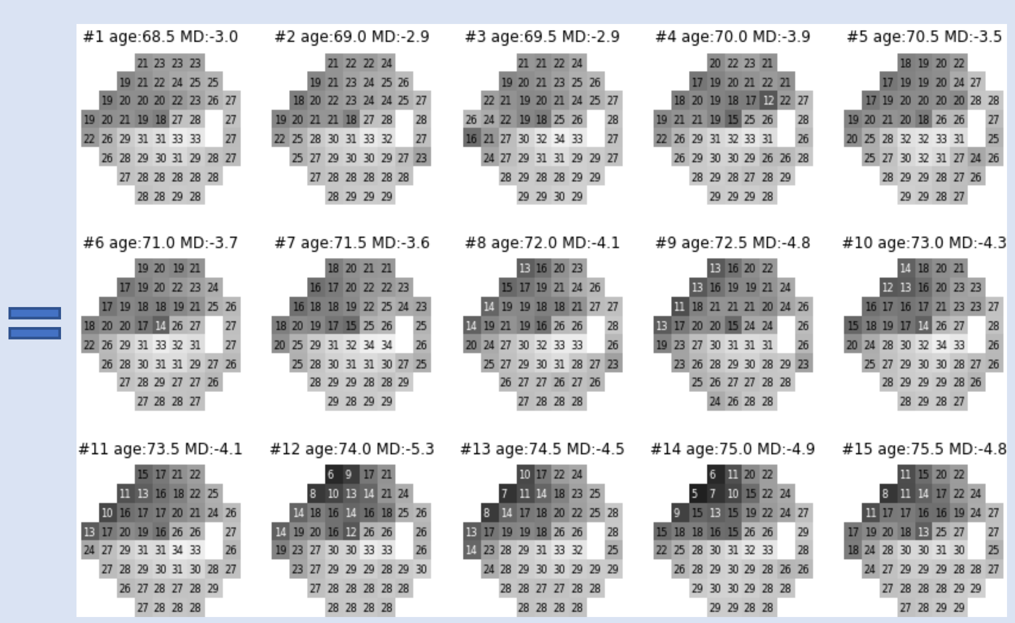

The spatial filter can smooth localized noise while not affecting the MD values.