New methods for an eye-tracker based on multiple corneal reflections

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Purpose:
Video oculography based on interpolation methods are widely used for gaze tracking purposes. Here we define new methods for a high resolution dark-pupil eye-tracker with multiple IR LED light sources to improve its accuracy and robustness against head movements and eyelid occlusion.

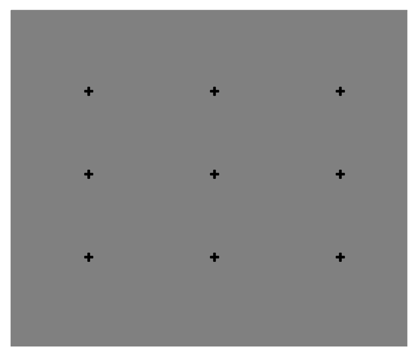
INTRODUCTION

- The Eye and Vision Analyzer (EVA) (DAVALOR, Spain) is a new 3D virtual reality system to assess human visual function. It embeds a dark-pupil based eye-tracker with twelve IR LEDs.
- Starburst algorithm [1] is a robust algorithm commonly used by the eye tracking community to track the eye position from infrared eye images.
- Normalization of the pupil-glint (PG) vector by the interglint distance has been shown to improve the accuracy of the eye-tracker, especially when head movement is allowed [2]. Can we improve it further?
- Is the use of twelve light sources justified by an improved eye-tracker's performance?

METHODS

- Eye images of seven subjects (age 20-29 years) were taken by means of current EVA's eye-tracker cameras (resolution: 640 x 480 pixels per eye, frame rate: 30 Hz) during calibration and validation procedures in which the subjects were asked to fixate a cross which appeared randomly on a 3 x 3 grid.
- All images have been processed offline with Starburst algorithm, which has been extended to fit EVA's eye-tracker requirements and characteristics.
- The point of regard (PoR) has been computed from the position of the pupil and glints with a second order interpolation equation.

Stimulus



Second order interpolation equation

$$\begin{pmatrix} PoR_x \\ PoR_y \end{pmatrix} = C \cdot \begin{pmatrix} 1 \\ V_x^2 \\ V_y^2 \\ V_x V_y \\ V_y \\ V_x \end{pmatrix}$$

C, calibration coefficients

$$V_x = p_x - g_x$$
$$V_y = p_y - g_y$$

- Different light sources configurations have been tested removing some corneal reflections by image processing (details in Table 1).

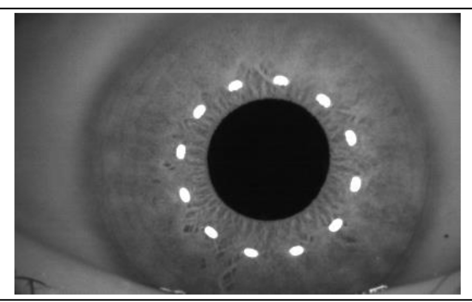
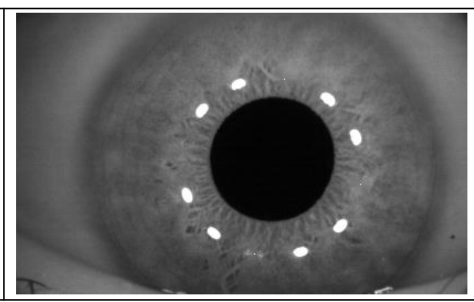
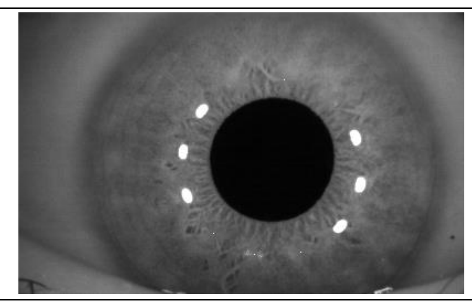
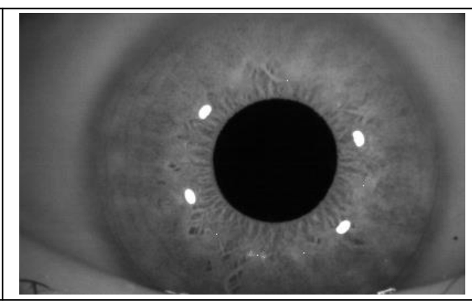
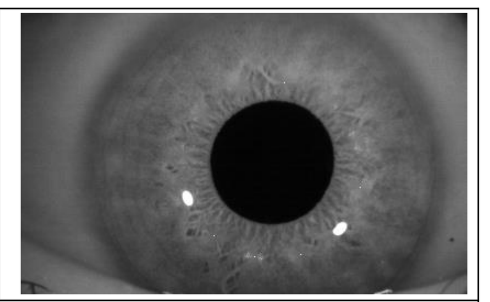
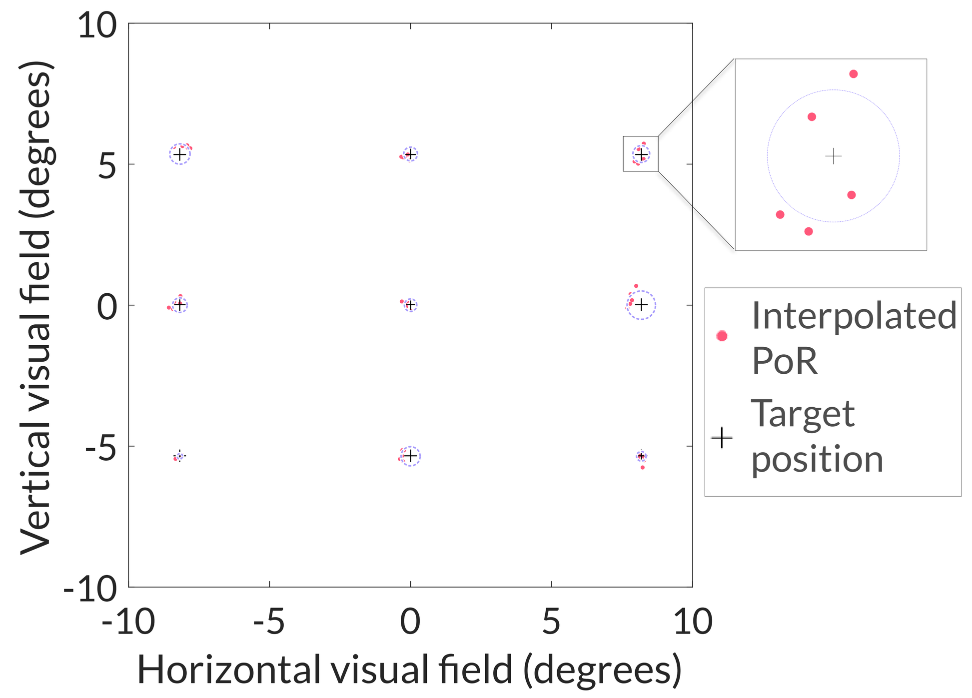
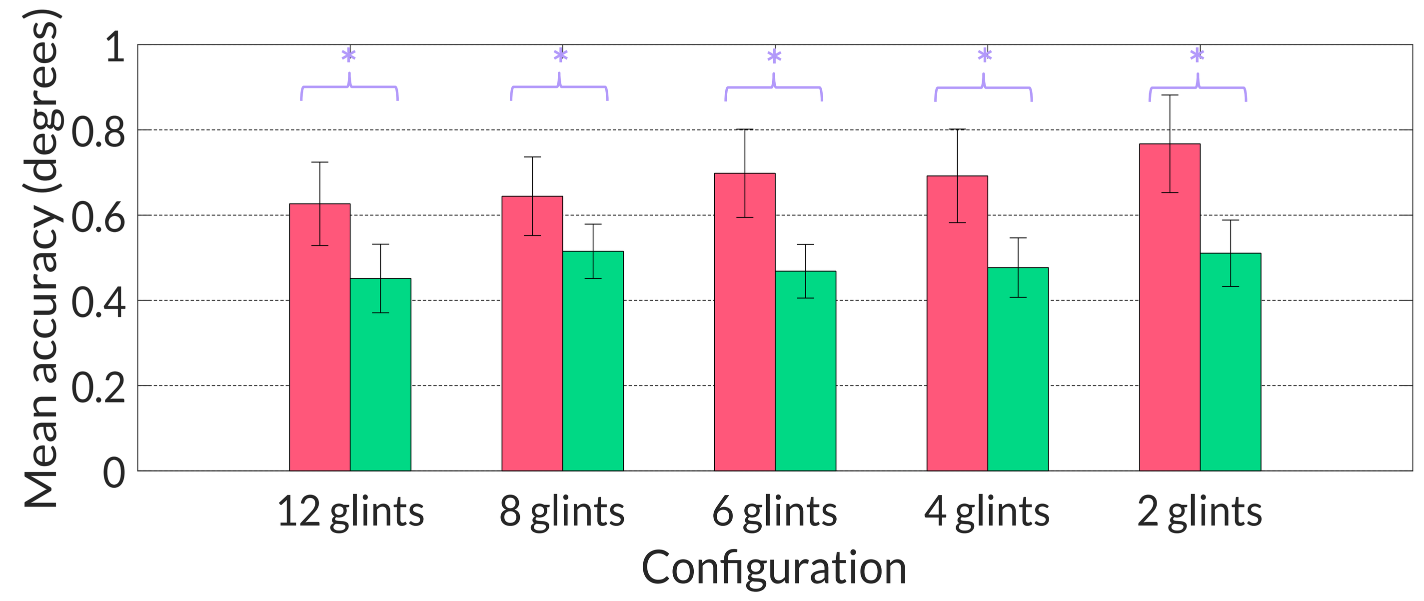
Number of glints					
Normalized PG vectors	$V_x = \frac{p_x - g_x}{r}$; $V_y = \frac{p_y(1-k) - g_y}{r}$		$V_x = \frac{p_x - g_x}{D}$; $V_y = \frac{p_y(1-k) - g_y}{D}$		
	g, **glints ellipse center** r, major radius of glints ellipse k, vertical weighting factor		g, **mean glints position** D, mean distance between opposite glints k, vertical weighting factor		

Table 1. Light sources configurations and normalization applied in each case.

RESULTS

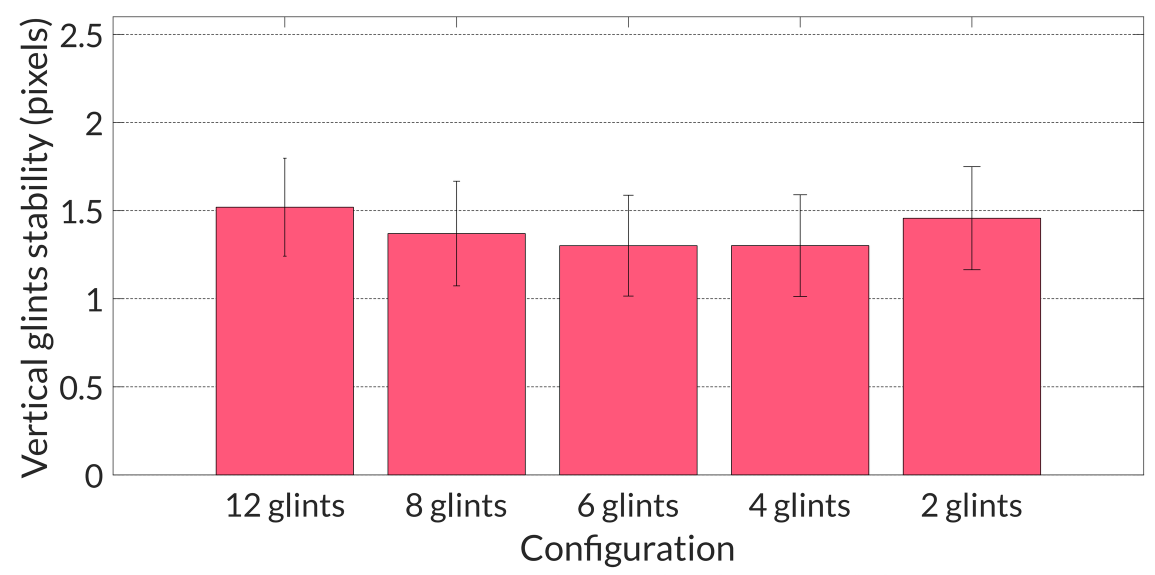
Accuracy: Euclidean distance between the target position and the PoR



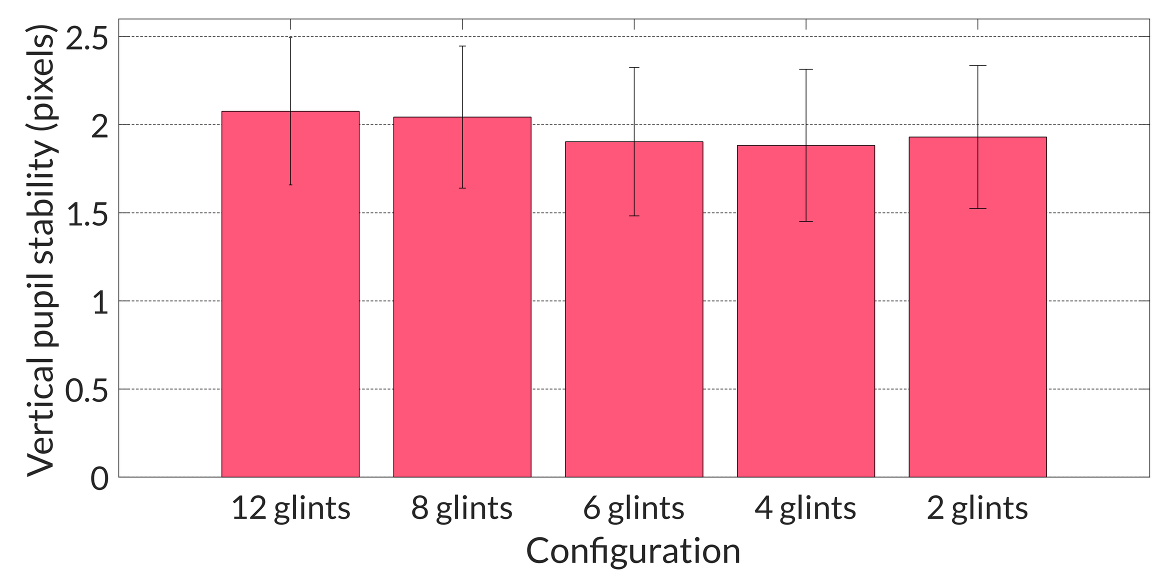


Error bars: +/- standard error of the mean
* Statistically significant differences
Without normalization / Normalized

Stability: Standard deviation of the pupil and glint coordinates at each calibration point



Error bars: +/- standard error of the mean



Error bars: +/- standard error of the mean

CONCLUSIONS

- The normalization of the PG vectors improves significantly the eye-tracker's accuracy in all five configurations. The improvement is greater in those configurations in which the real positions of the glints are considered, i.e. with 2, 4 and 6 glints.
- The accuracy tends to increase with the number of glints (although not significantly here, for n=7 subjects), especially when normalization is not applied. However, the best results in terms of pupil and glints stability are shown with 4 and 6 glints.
- These trends need to be confirmed with a larger eye images database in order to determine which is the best light sources configuration.

REFERENCES

1. Li, D., Winfield, D., & Parkhurst, D.J. (2005). *Proc. Vision for Human-Computer Interaction Workshop, IEEE Computer Vision and Pattern Recognition Conf.*
2. Sesma-Sanchez, L., Villanueva, A., & Cabeza, R. (2012). *IEEE Transactions on Biomedical Engineering*, 59(8), 2235-2243

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