Enhancing the precision of remote eye-tracking using iris velocity estimation

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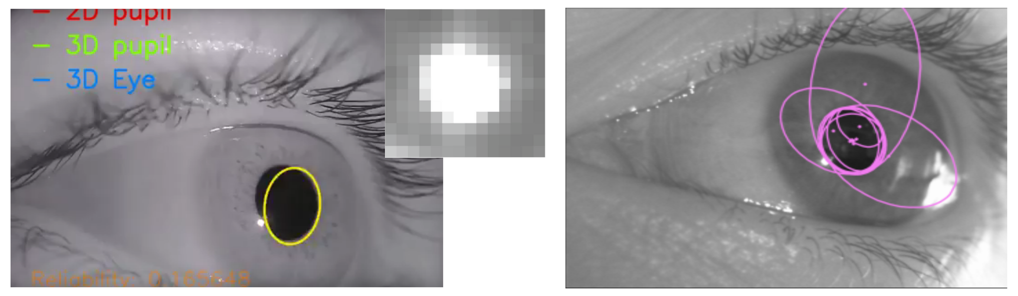
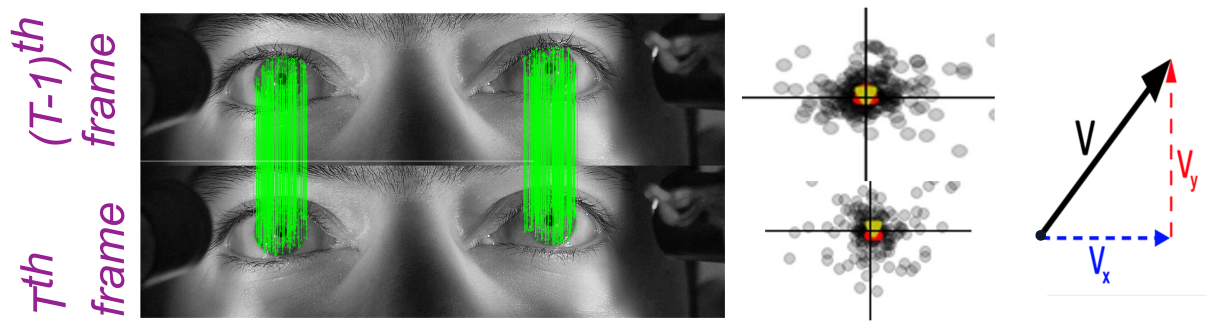
Overview

- Reliance on only **pupil or pupil & corneal reflection (CR)** in current methods result in **high variance**



Signal quality is affected by improper ellipse fits as well as error in center estimation of CR. Image credits: [3][4]

- Pelz & Witzner Hansen (2017)[2] and Chaudhary & Pelz (2019)[1]
  - -> tracked **large number of iris features**
  - -> **motion vectors**
  - -> **velocity over time**
  - -> **integrated** velocity to get position
  - -> **improved temporal precision**



Features are matched in consecutive frames. Motion vectors are approximated representing the motion of each feature. Velocity is obtained from motion vectors.

- Problems
  - -> temporal **drift** (small error in approximation of velocity)
  - -> insufficient matches of iris features due to **motion blur**
  - -> issues during **blinks**

Proposed Method

- Merge traditional **P-CR** with **Iris velocity**-based systems
- **P-CR** -> Does **not** drift but **low precision**
- **Iris velocity**-> **High** precision but **drifts over time**
- ***Modified* Kalman Filter** -> effective combination of low frequency components of P-CR with high frequency components of iris velocity based method

$$\pi_t = Pi_t = \Sigma(\underbrace{\beta_P I(P\text{-}CR)}_{\text{Pupil Information}}+\underbrace{\beta_I D^T D(I_v - H_v)}_{\text{Iris Information}})$$

Pupil Center (P), corneal reflection (CR),

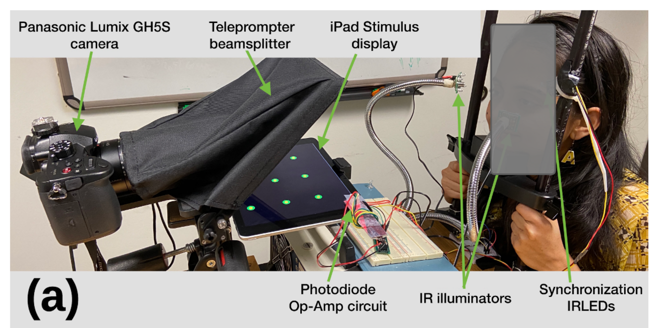
Iris velocity (I_v), head velocity (H_v)

D: spatial gradient

I: identity matrix

β_P & β_I are hyperparameters

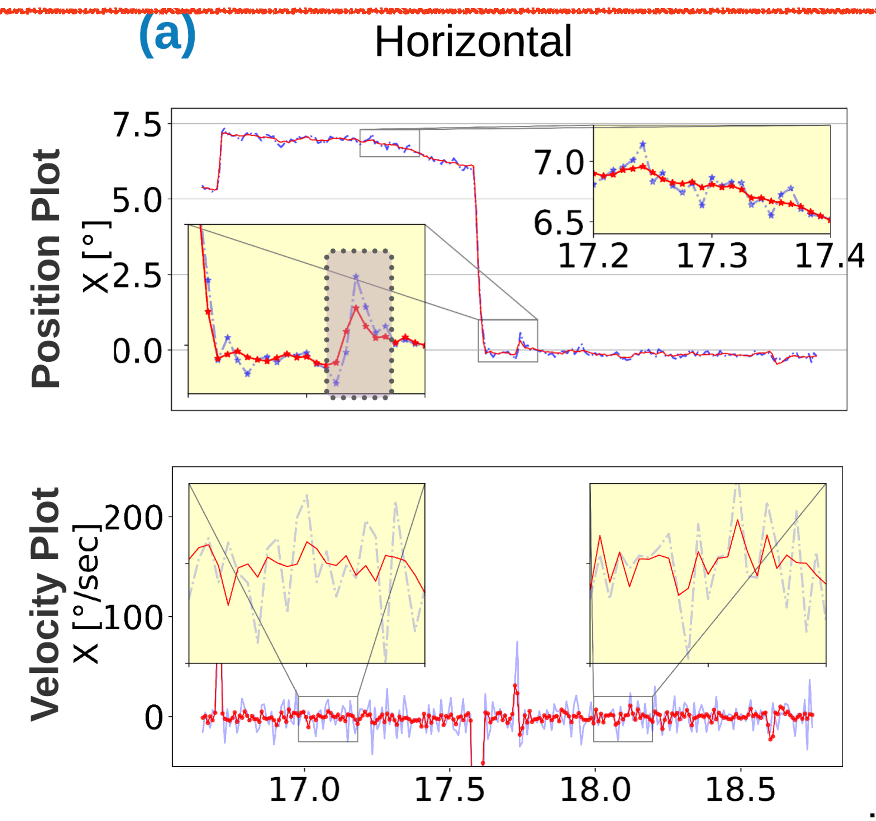
Σ: covariance matrix



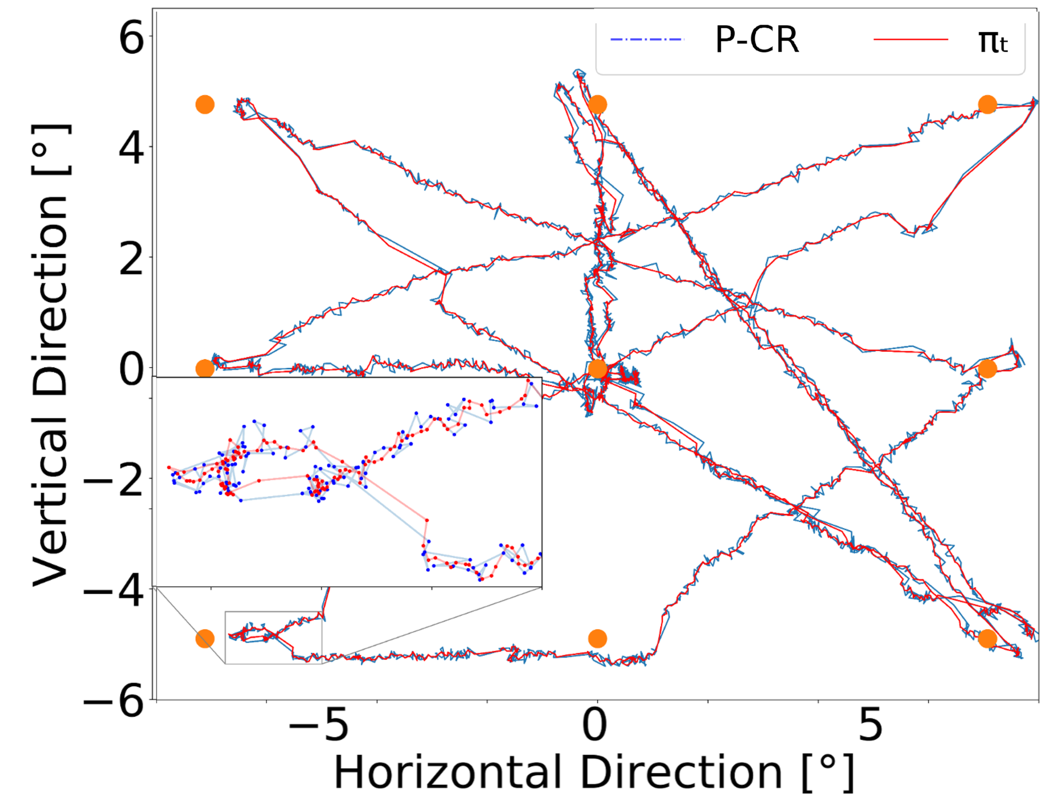
Experimental setup to extract high quality iris textures

Results

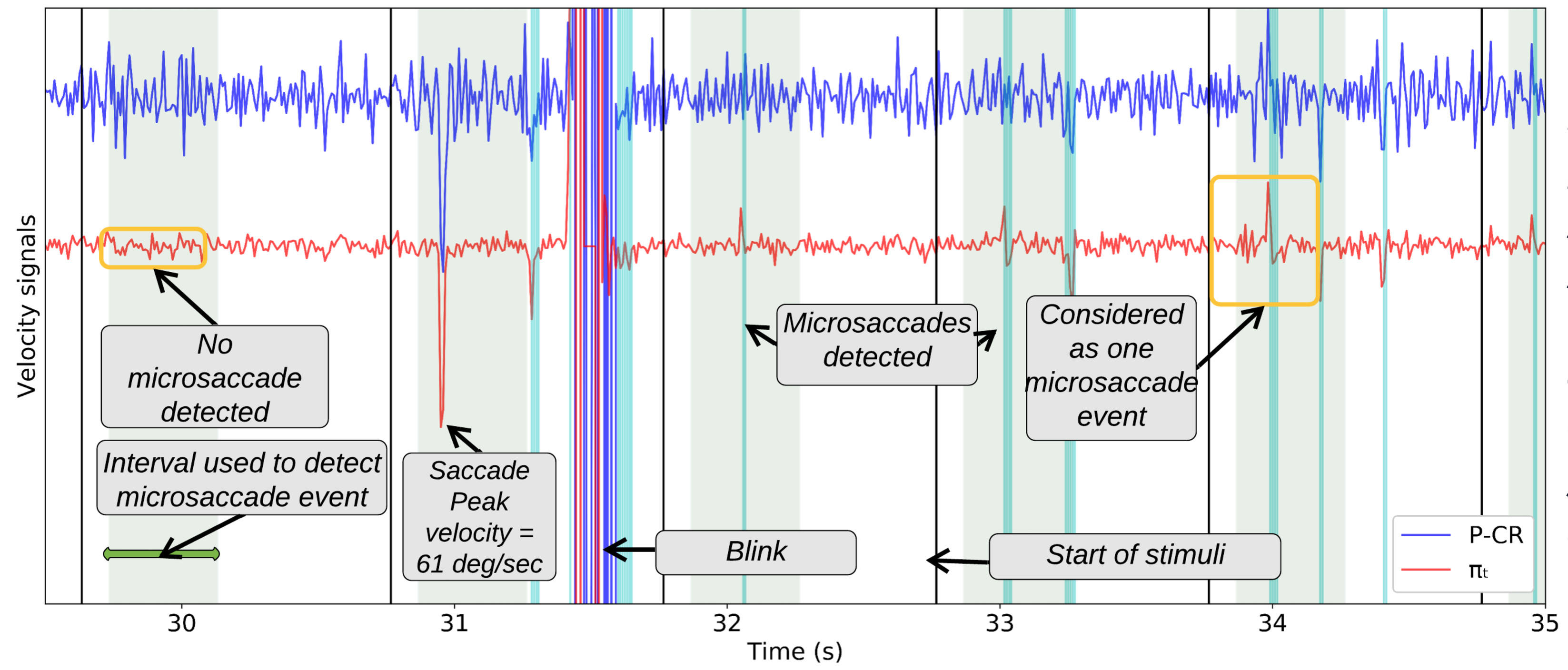
- Calibration Verification Task
  - Comparable accuracy to P-CR
  - Improved Precision (S2S-RMS +55%, STD 23 %)
- Smooth Pursuit Task
  - Improved Precision (S2S-RMS +48%, STD 10 %)
- Microsaccade Detection Task
  - 73% of microsaccades of 0.2-degree were detected
  - Some events had simultaneous head and eye movement and were undetected
- Simulation Result
  - A_{noise} (like P-CR)
  - B_{drift} (like iris-based)



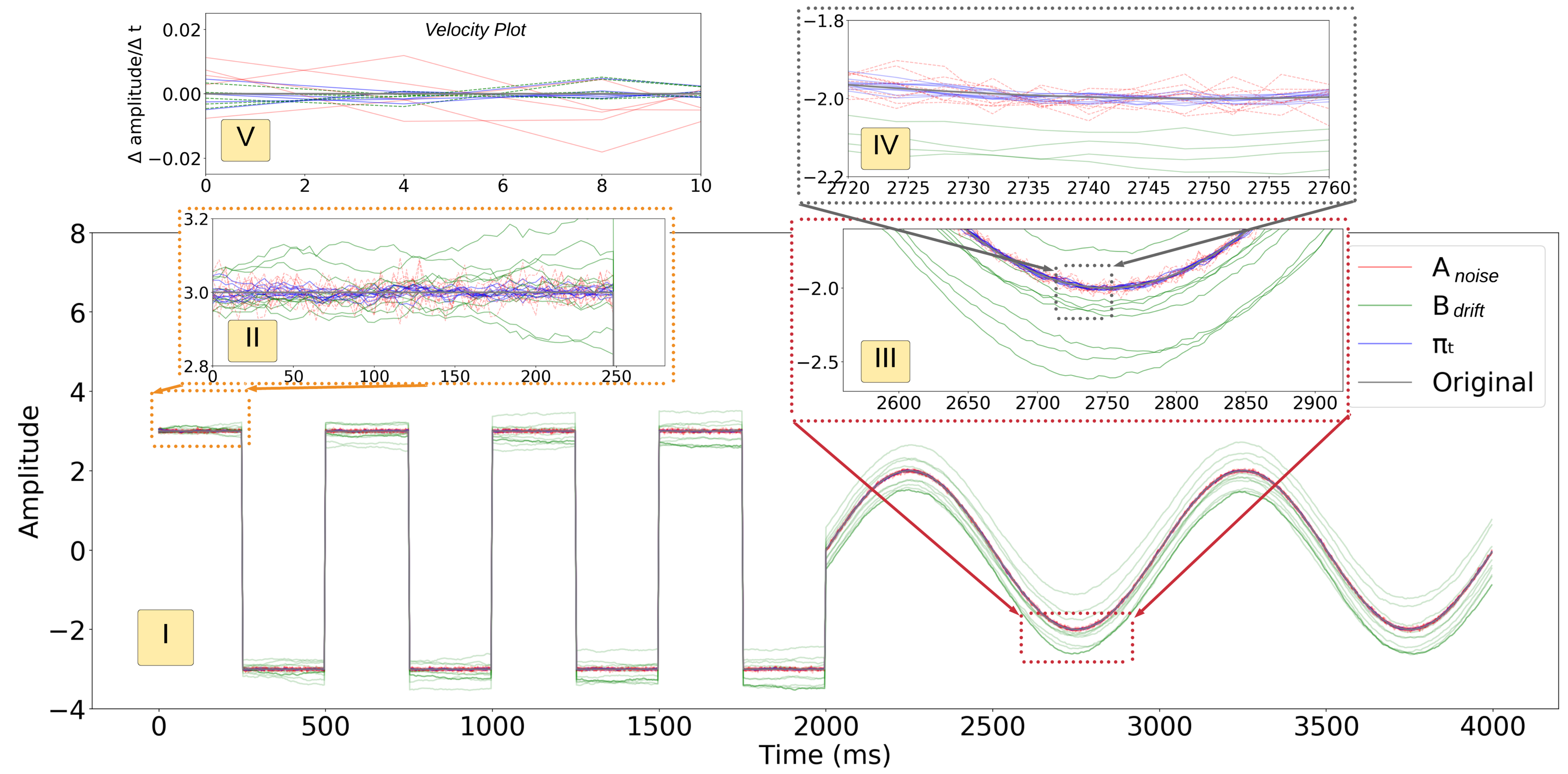
Comparison of position and velocity obtained from our method with P-CR. Each zoomed-in section (in yellow) is 200 ms in duration (4×)



Gaze map of eye movements during a smooth pursuit task for one participant.



The velocity signals for P-CR and the π_t model. Each microsaccade event starts with a display of a stimulus (black line). The time period where an event is likely to occur is indicated in green and the detected microsaccade is indicated in cyan.



Signal A has spatial noise (dashed red lines visible in block II indicated in a yellow box), signal B has temporal drift (solid green lines visible in block III indicated in a yellow box). The derived signal output (blue lines, distinguishable in zoomed-in blocks IV (position signal) and V (velocity signals) handles the temporal drift and minimizes the spatial noise

Conclusion

- Presented a **new mathematical formulation** to solve issues of **signal drift, insufficient feature matches** during **motion blur** and **blinks** -> **No issues of temporal signal latency**
- High frequency component of iris velocity based method combined with low frequency components of Pupil -> **Improved Precision without degrading accuracy**

Our Presence at ETRA 2021

- Privacy-Preserving Eye Videos using Rubber Sheet Model (Short Paper)
- Semi-Supervised Learning for Eye Image Segmentation (Short Paper)
- RIT-Eyes, realistically rendered eye images for eyetracking applications (Video)

References

1. Chaudhary, A. and Pelz, JB. 2019. Motion tracking of iris features to detect small eye movements. Journal of Eye Movement Research12,6(Apr.2019)
2. Pelz, JB & Hansen, DW. 2017. System and method for eye tracking. International Patent Application No. PCT/US2017/034756 (2017).
3. *Eskisehir, Turkey.*Holmqvist, K., & Blignaut, P. (2020). Small eye movements cannot be reliably measured by video-based P-CR eye-trackers. *Behavior research methods*, 1-24.
4. Topal, C., Cakir, H., & Akinlar, C. (2017). An Adaptive Algorithm for Precise Pupil Boundary Detection using Entropy of Contour Gradients$. *Department of Computer Engineering, Anadolu University,*