Blink Detection in Pupillometry Data to Advance the Use of Quantitative Measurements of Pupil Size and Dynamics

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Background

- ❑ Light input to the brain is important for many types of physiology, including circadian rhythms, mood, and alertness.
- ❑ Light input to the brain is gated by the pupils of the eye dilating (more light transmission) and constricting (less light transmission).
- ❑ The current standard for measuring pupil responsiveness to light is to waive a penlight in from of one eye and see if that eye and/or the other eye's pupils constrict. Given that that pupil response is a time varying response, we decided to use pupillometry to quantify pupillary response to light of different intensities, durations, and wavelengths.
- ❑ Pupil diameter is measured using a commercially available pupillometer. Red or blue wavelengths of light are presented to one eye and pupil diameter is measured from both eyes. Pupillary data must be cleaned of eye blinks before analyses can be done.

Introduction

- ❑ There is no standardized approach for classifying and filtering blinks or other noise artifacts from pupillometry signals.
- ❑ The purpose of this project is to develop a blink detection algorithm that operates on the raw pupil diameter signal and to evaluate the algorithm's performance.
- ❑ The algorithm used to filter the data will be released as free and open-source software.

Research Questions

- ❑ How can we categorize and quantify the artifacts and noise present in the signal?
- ❑ Which algorithm(s) can be used to detect these features?
- ❑ How can we evaluate the performance of the filter?

Filter Design

❑ 1st stage - Velocity-based detection

Blink artifacts are identified using a velocity-based criterion applied to the pupil diameter signal. For each pupil, $X \in \{\mathrm{Left}, \mathrm{Right}\}$, the instantaneous pupil velocity is computed as the first temporal derivative of the diameter, defined as the frame-to-frame change in pupil size normalized by the corresponding change in time:

$$V_{X,t} = \frac{X_t - X_{t-1}}{\Delta t_t}, \ \Delta t_t = t - t_{t-1}$$

Samples with velocities lower than a constriction threshold or higher than a dilation threshold are classified as part of a blink:

$$B_{X,t} = \begin{cases} 1 & \text{if } V_{X,t} < v_{\text{constr}} \ \vee \ V_{X,t} > v_{\text{dilate}} \\ 0 & \text{otherwise} \end{cases}$$

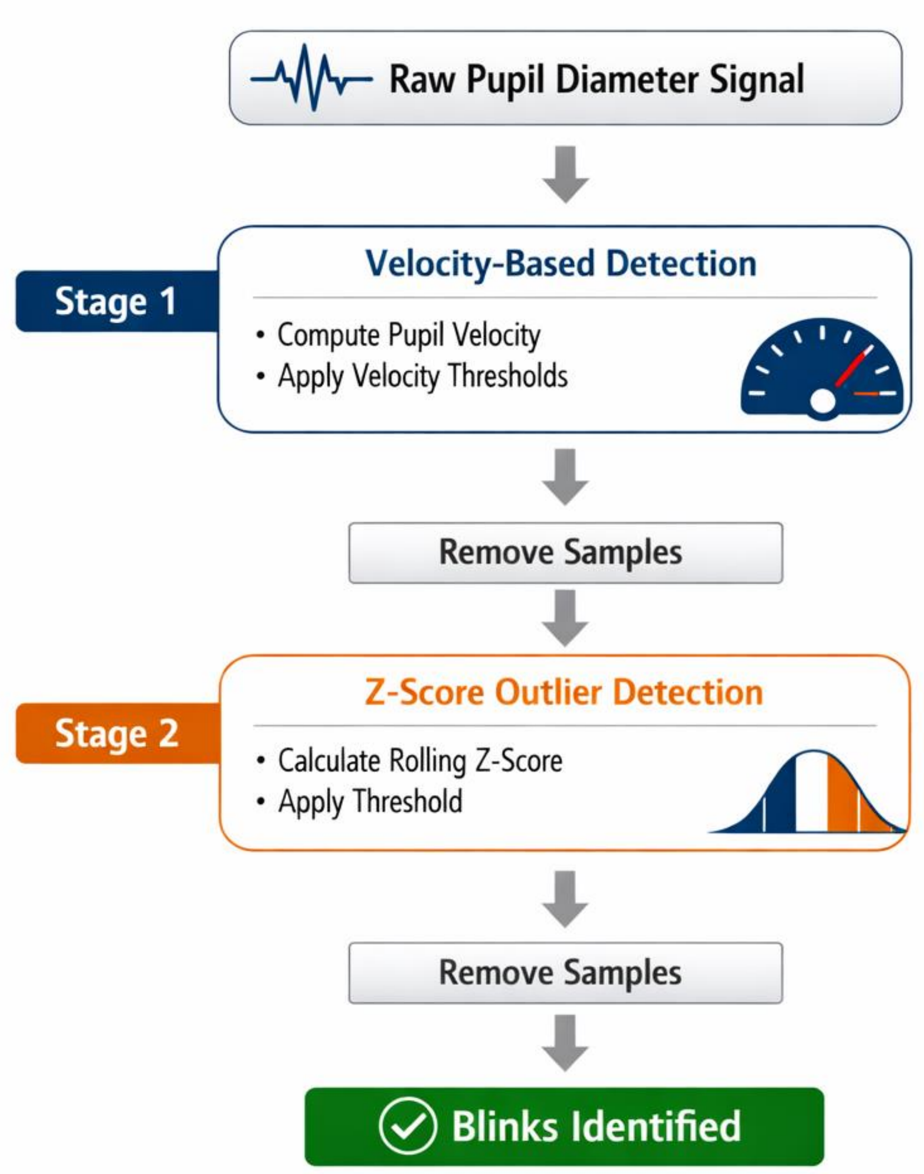
This method exploits the characteristic rapid decrease and rebound in measured pupil size caused by eyelid occlusion, enabling the detection of blink artifacts that may not be captured by amplitude-based approaches.

❑ 2nd stage - Outlier-based detection (Rolling Z-Score)

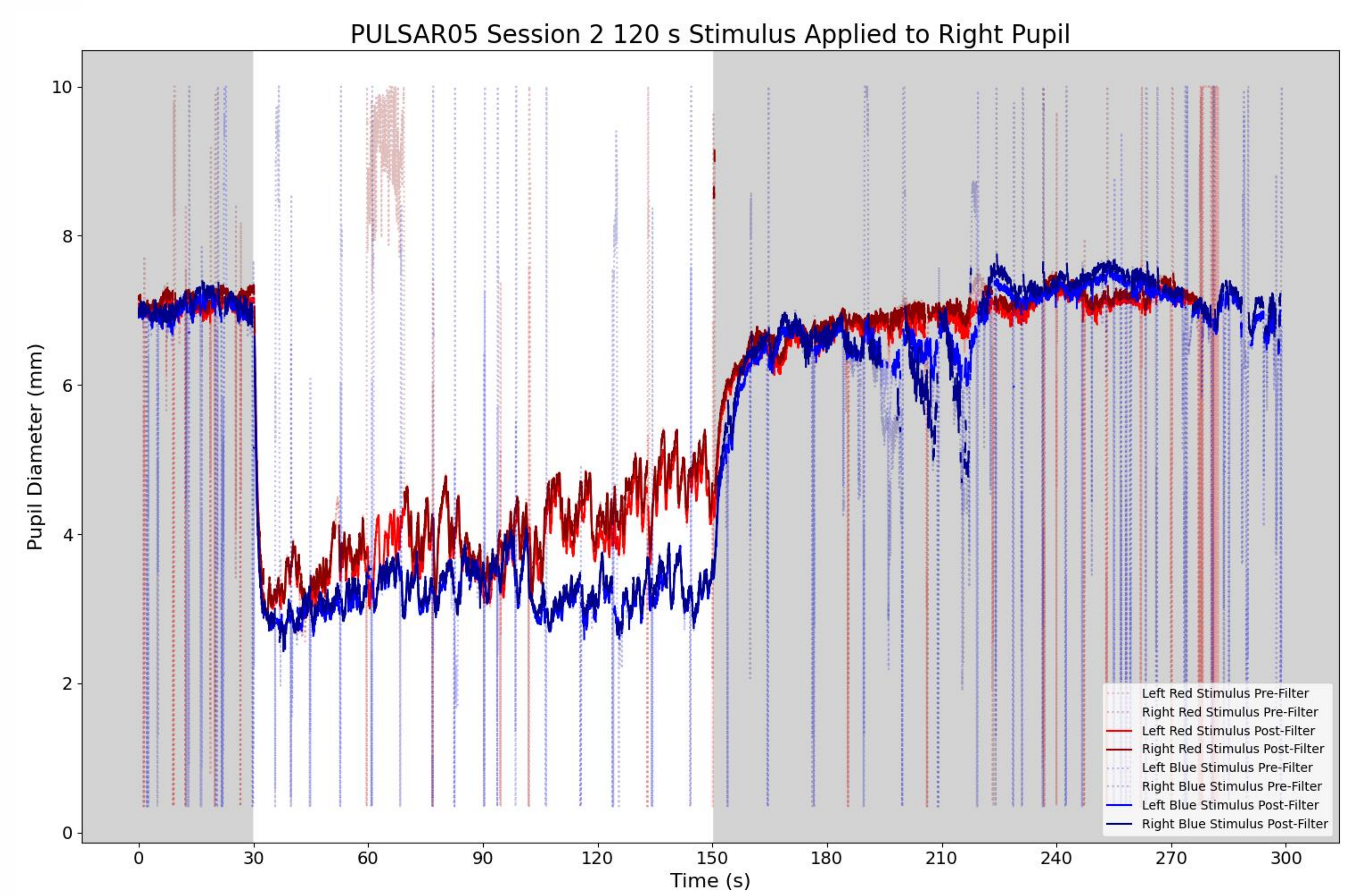
For each pupil, $X \in \{\mathrm{Left}, \mathrm{Right}\}$, a rolling mean, $\mu_{X,t} = \mathrm{rollingmean}(X_t, w)$, and standard deviation, $\sigma_{X,t} = \mathrm{rollingstd}(X_t, w)$, are computed over a window of size w. A sample is detected as part of a blink when the pupil diameter deviates more than k standard deviations from its rolling mean:

$$Z_{X,t} = \frac{X_t - \mu_{X,t}}{\sigma_{X,t}}, \ B_{X,t} = \begin{cases} 1 & \text{if } |Z_{X,t}| > k \\ 0 & \text{otherwise} \end{cases}$$

Two–Stage Blink Detection Pipeline



Plot of a stimulus run before and after filter application



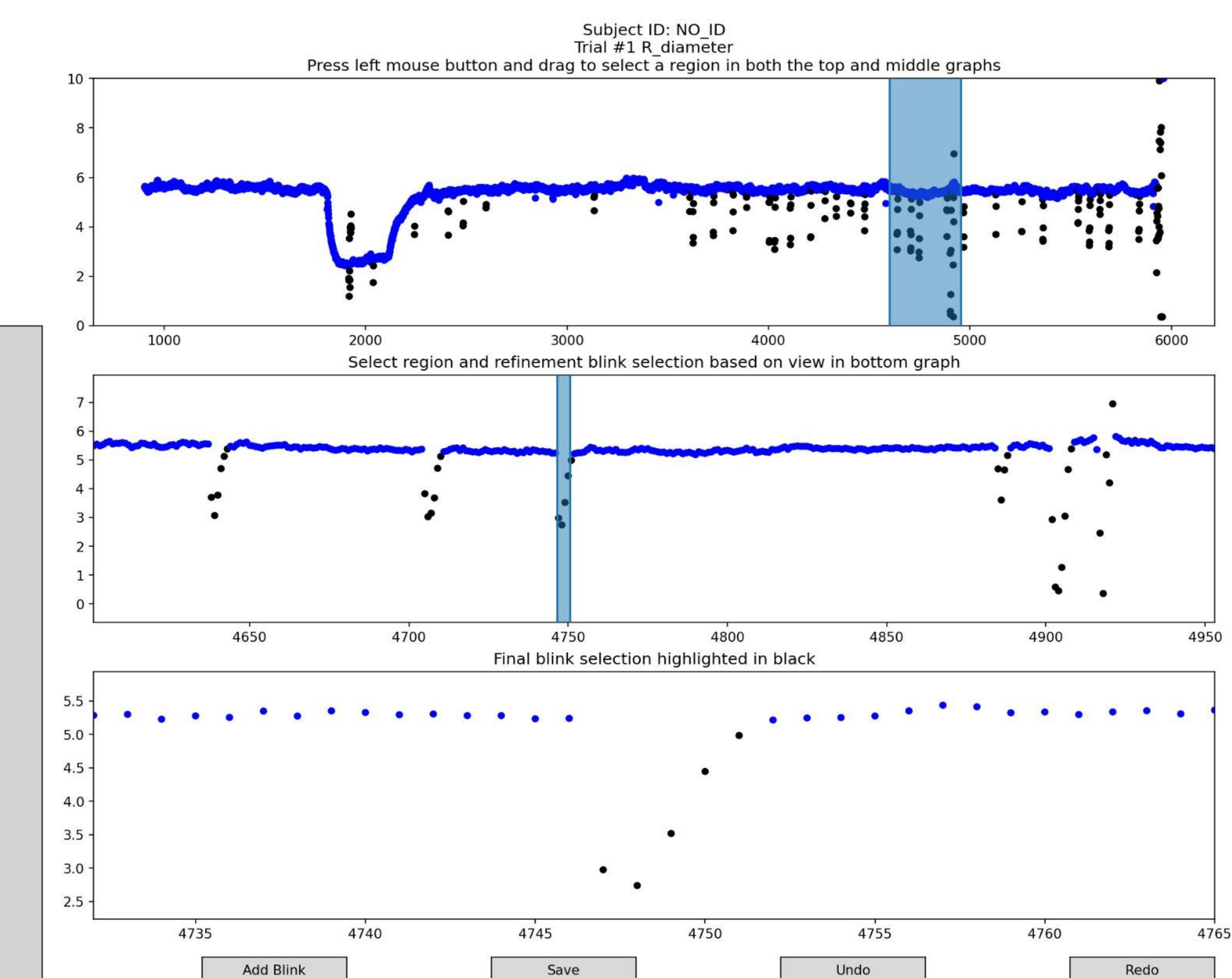
- ❑ A stimulus run consists of 30 seconds of baseline pupil diameter, a variable length stimulus length, and 120 seconds of recovery to baseline.
- ❑ The raw signal is plotted as a dotted line for each stimulus color
- ❑ The cleaned signal is plotted as a solid line for each stimulus color.
- ❑ Data are collected from both left and right eyes for each red or blue stimulus.

Filter Performance Evaluation

- ❑ Actual classes were generated by manually detecting artifacts across a subset of the dataset
  1. Frequency of artifacts in:
     - Baseline Phase
     - Stimulus Phase
     - Recovery Phase
  2. Variance in Stimulus Duration and Color
- ❑ Performance Metrics Calculated:

Constriction Velocity (mm/s)	Dilation Velocity (mm/s)	Window Size	k	Sensitivity	Specificity	F_1 Score
-6	1	270	2.5	0.891	0.781	0.135

User interface for generating actual classes. Samples marked as part of a blink are recolored in black.



Future Work

- ❑ Filter out smaller, high frequency oscillations in pupil diameter.
- ❑ Improve accuracy and precision of filtering.
- ❑ Determine and apply the best approach for filtering sustained deviations in pupil diameter from the signal.