Tracking the Dynamics of the Tear Film Lipid Layer

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My Amazing Collaborators

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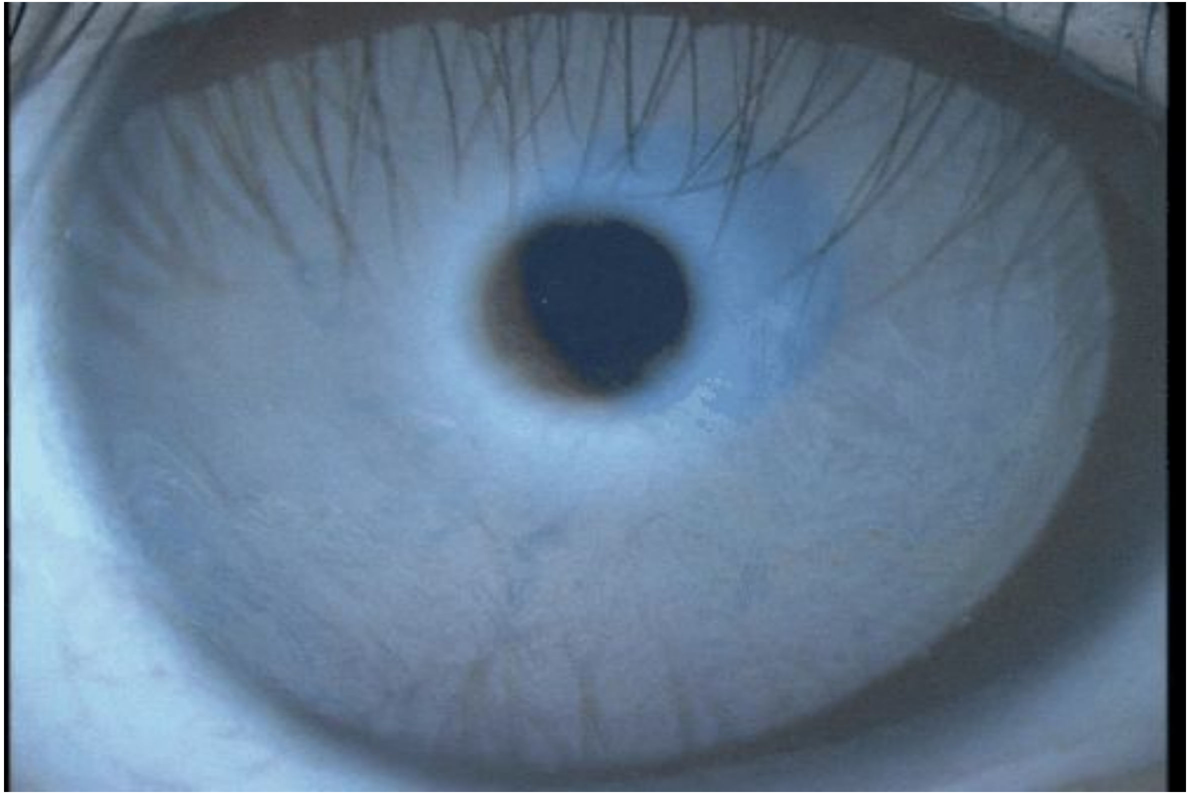
BERKELEY
OPTOMETRY

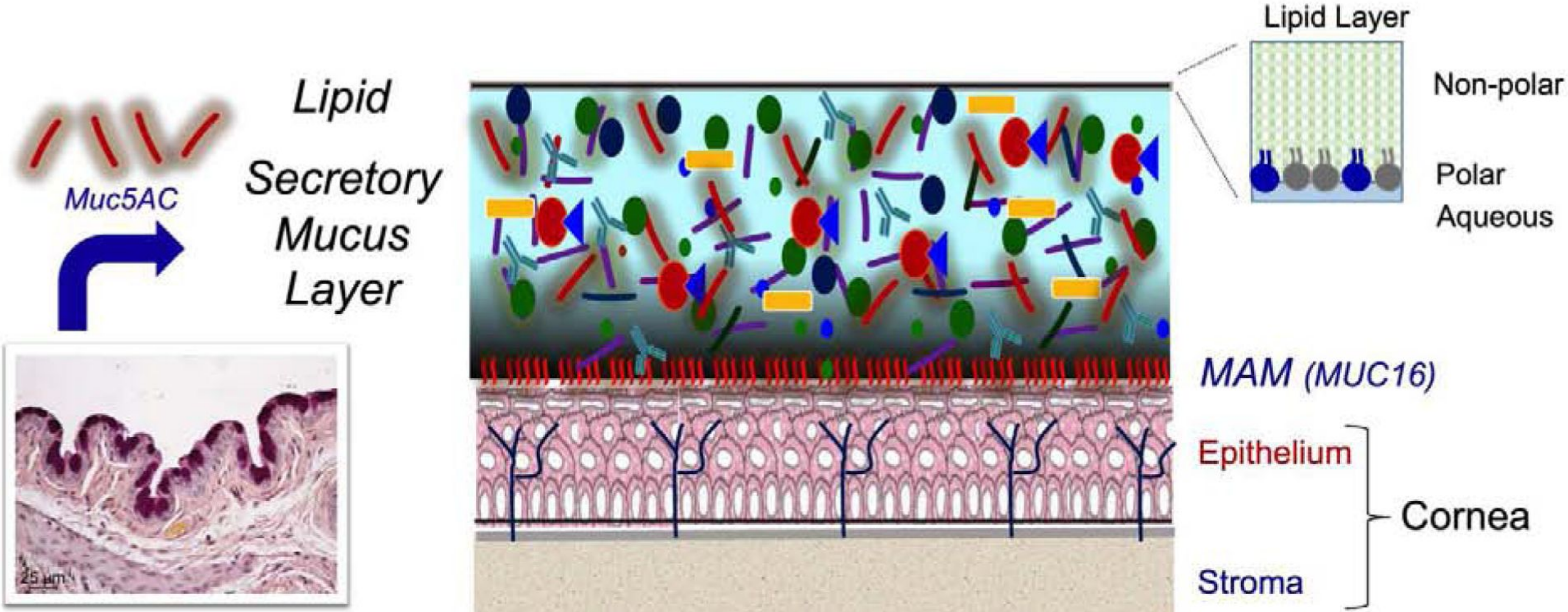
Background

Tear Film Lipid Layer Visualized



Tear Film Lipid Layer Visualized (cont.)

Tear Film Diagram



Conjunctival Goblet Cells

Prior Work in Lipid Layer Motion Tracking

[1] Norihiko Yokoi et al. “Rheology of tear film lipid layer spread in normal and aqueous tear– deficient dry eyes”

Prior Work Conclusions

- *In all cases, the time-dependent changes in TFLL spread could be described by the expression* ***H(t) - H(0) = ρ[1 - exp(t/λ)]****, where* ***H(t) is the averaged height*** *in millimeters at time t, H(0) is the averaged height at t 0, is a constant, t is time in seconds, and is the characteristic time in seconds.* [1]

- ***spreading time is longer in aqueous-deficient dry eyes*** *than in aqueous-sufficient normal eyes.* [2]

- ***spreading is affected by aqueous tear volume*** [2]

[2] Goto E, Tseng SC. Kinetic analysis of tear interference images in aqueous tear deficiency dry eye before and after punctal occlusion.

Our Proposal

This work proposes a novel paradigm in using **computer vision techniques to numerically analyze the tear film lipid layer spread**

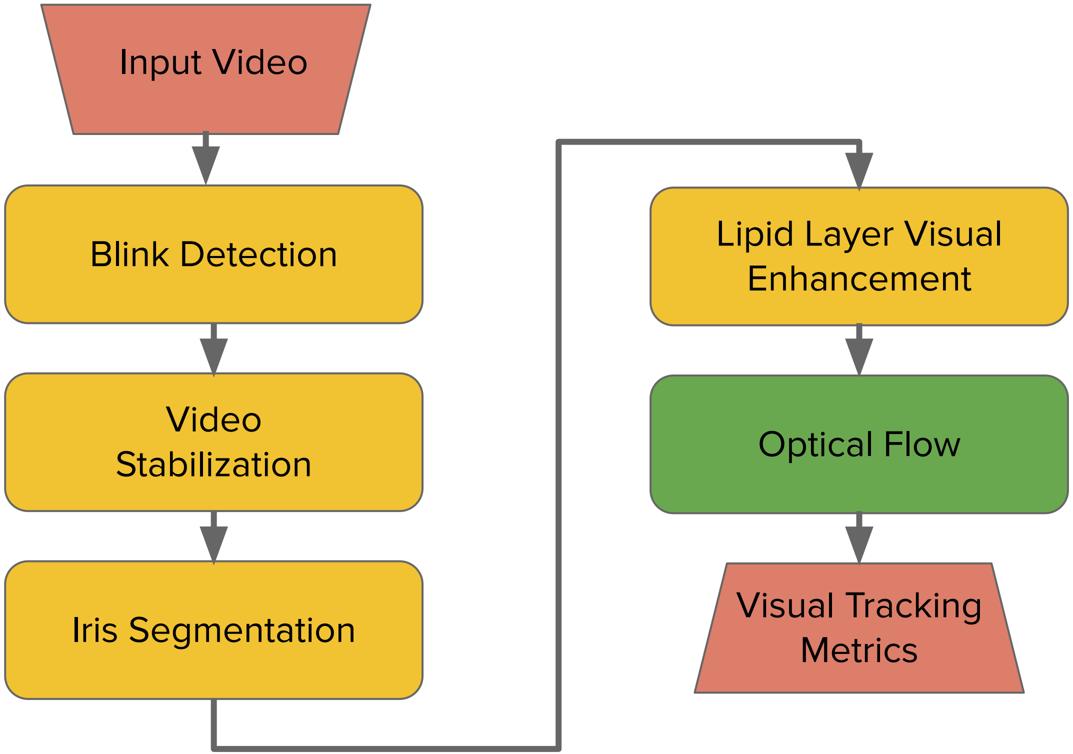
Methodology

Data Collection

EasyTear View

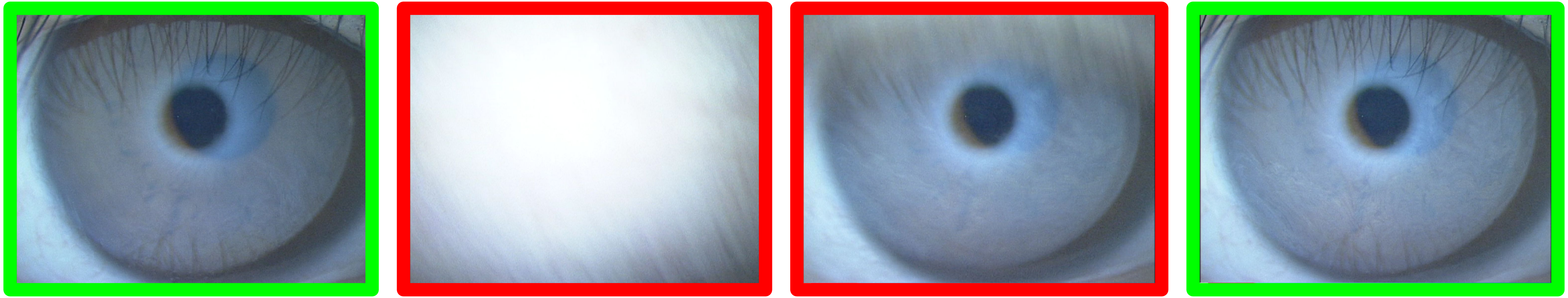
- ➢ Three Interblink Periods Collected in One Video

Methodology Pipeline



Preprocessing

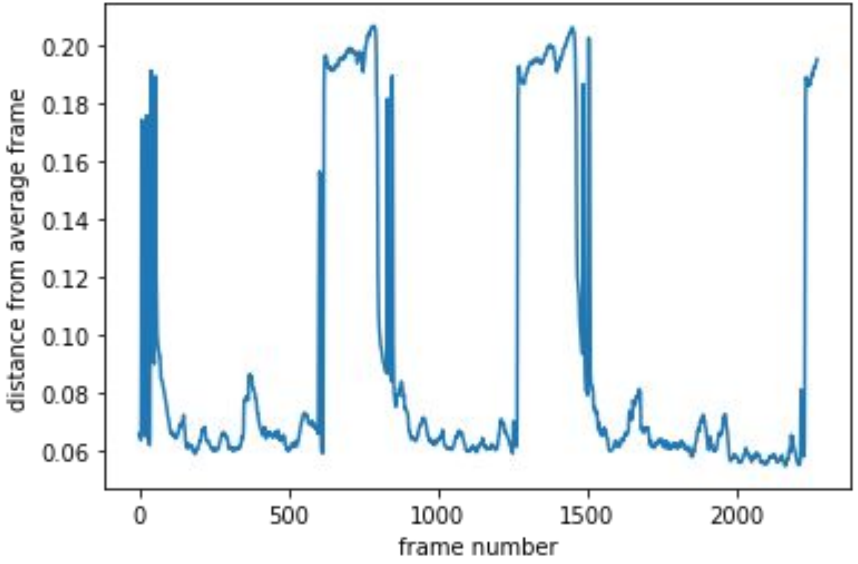
Blink Detection

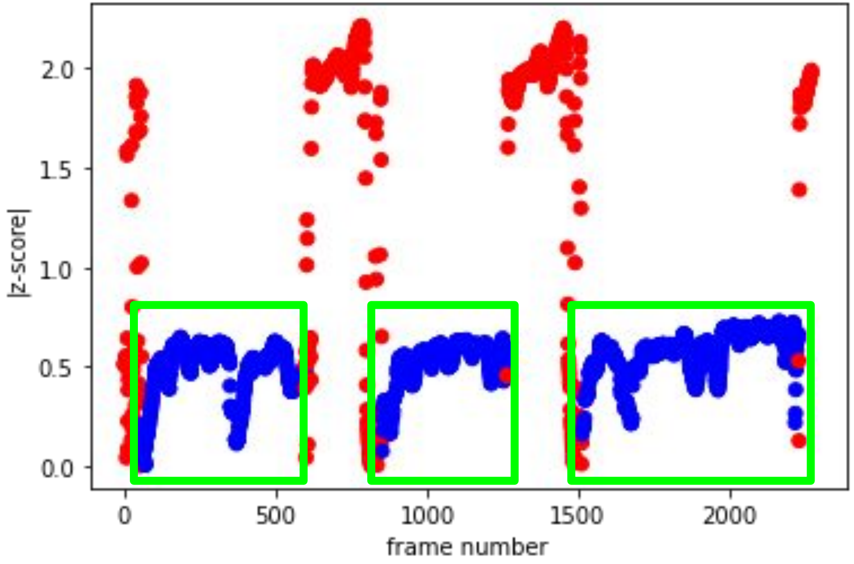


Blink Frame

Inter-Blink Frame

Blink Detection (cont.)

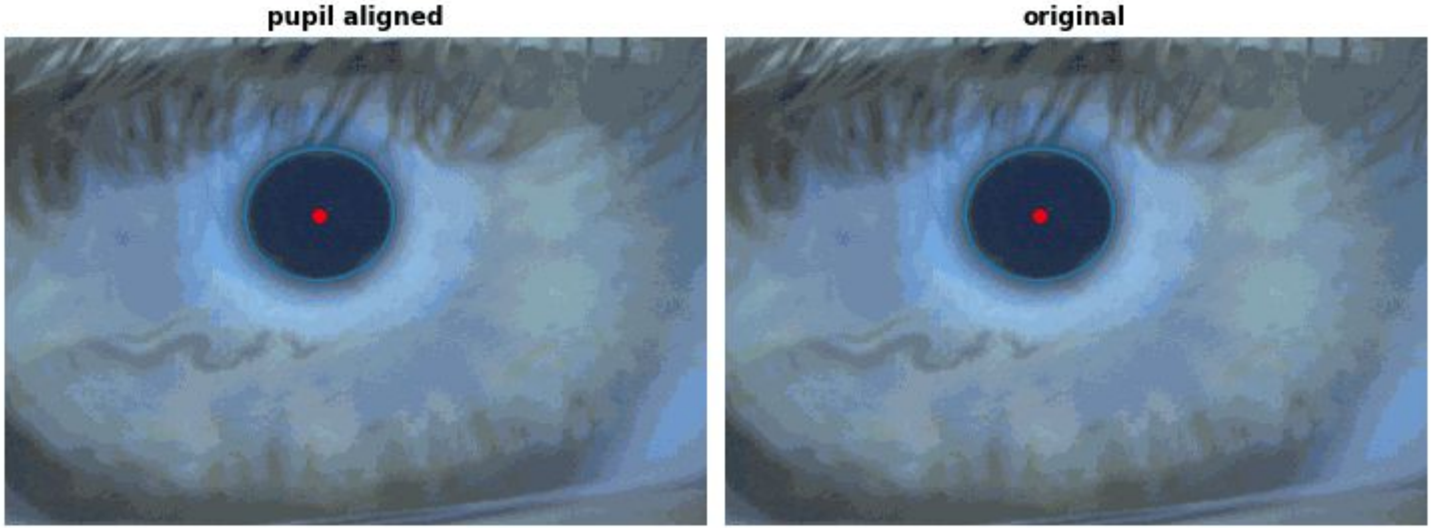


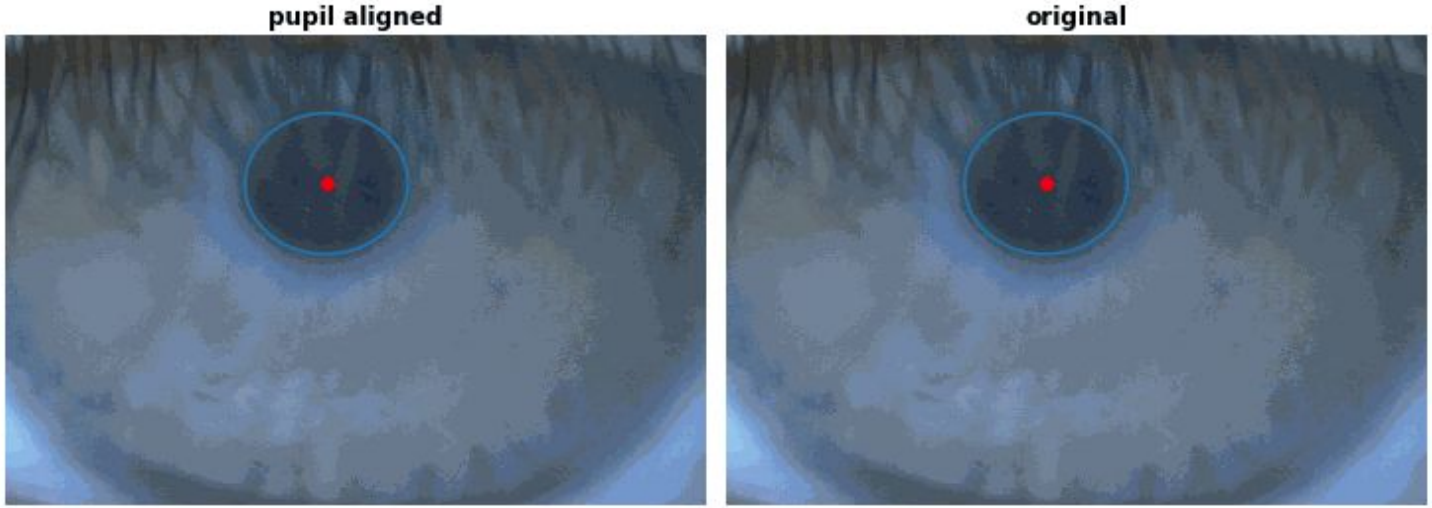


Video Stabilization with Pupil Tracking [2]

[2] Bartlomiej Kowalski et al. *Hybrid FPGA-CPU pupil tracker*

Video Stabilization with Pupil Tracking (cont.)


pupil aligned
original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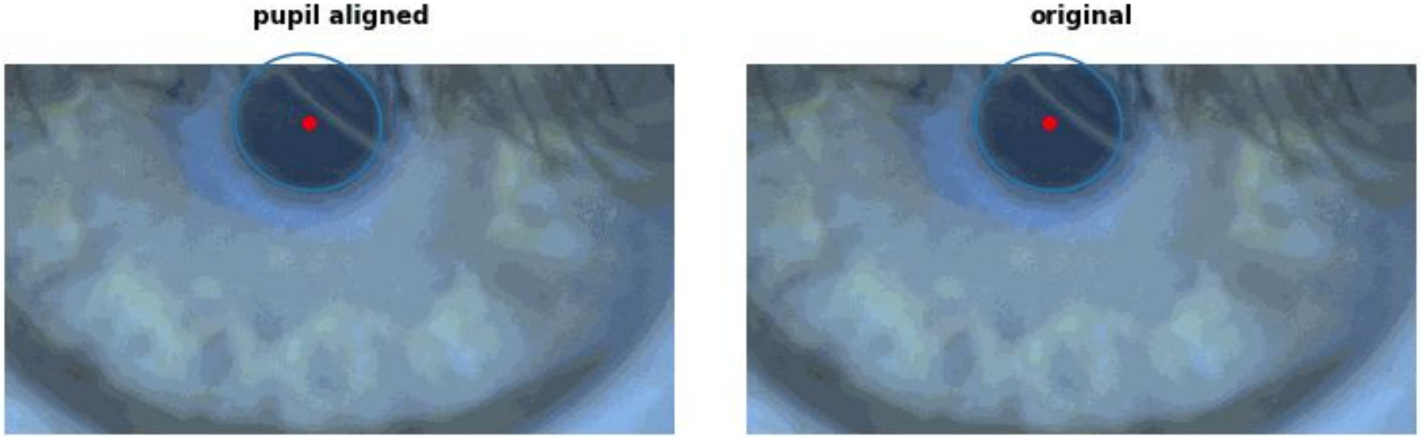
original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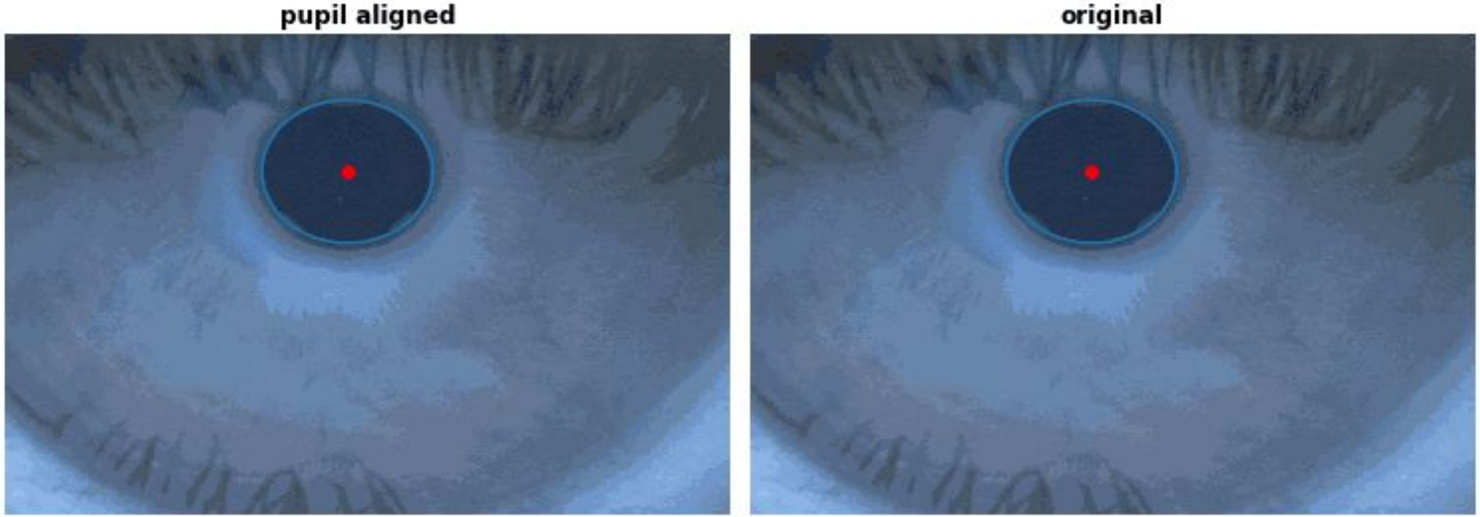
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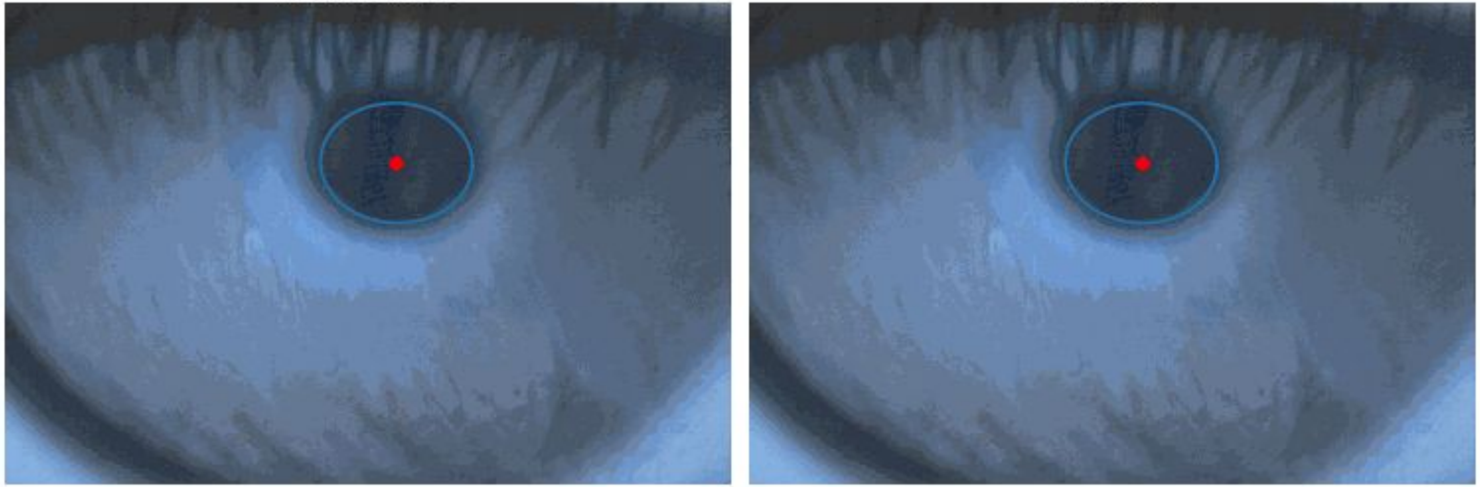
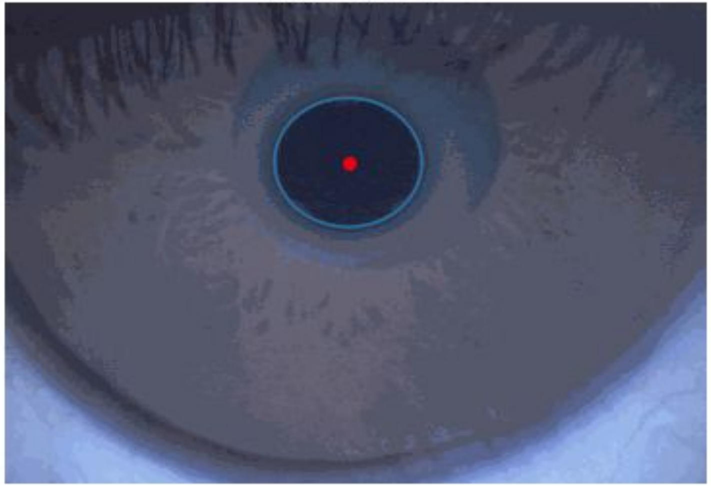
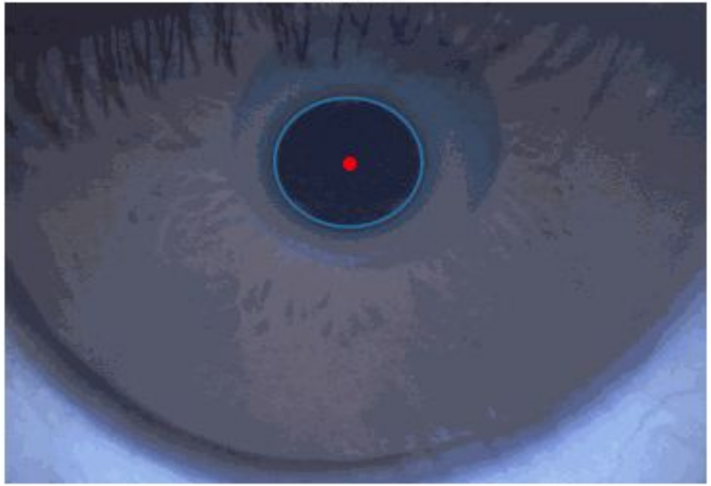
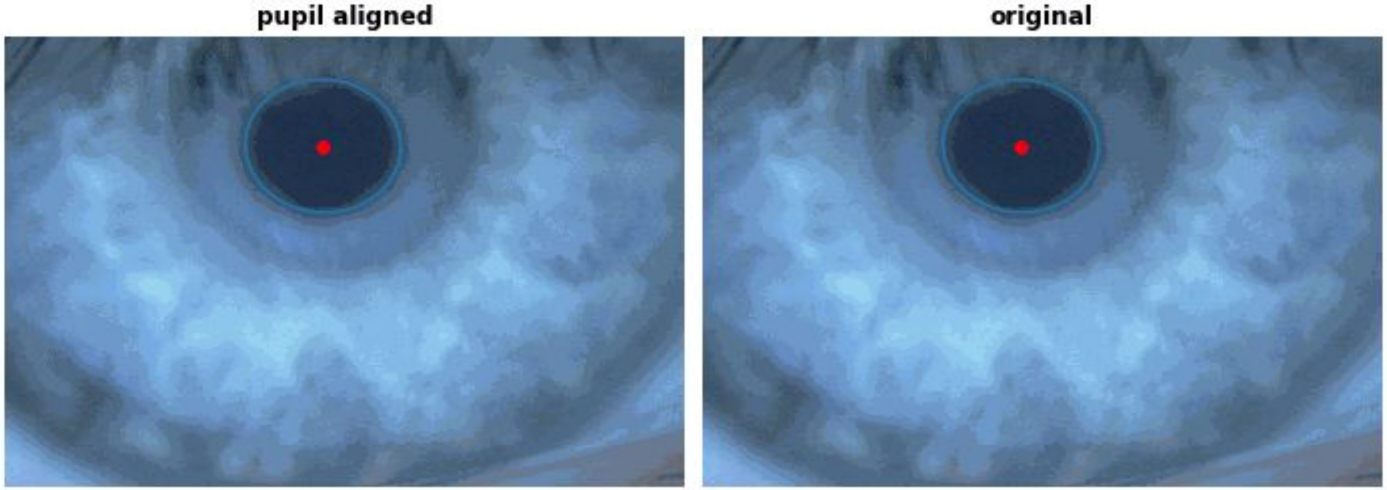

pupil aligned
original

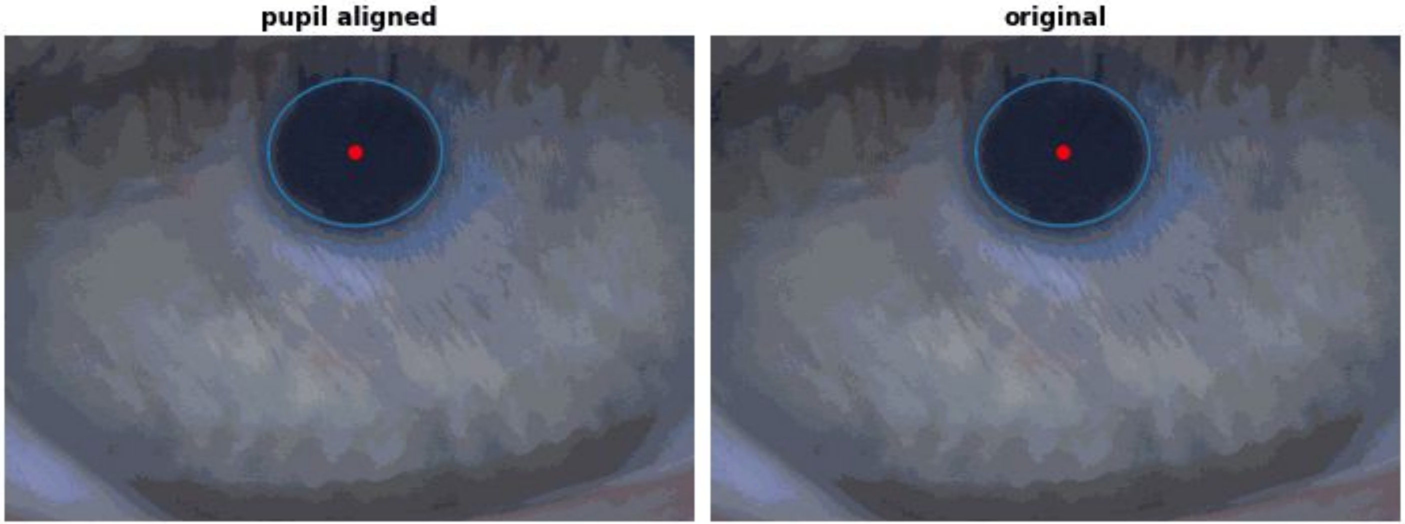
pupil aligned

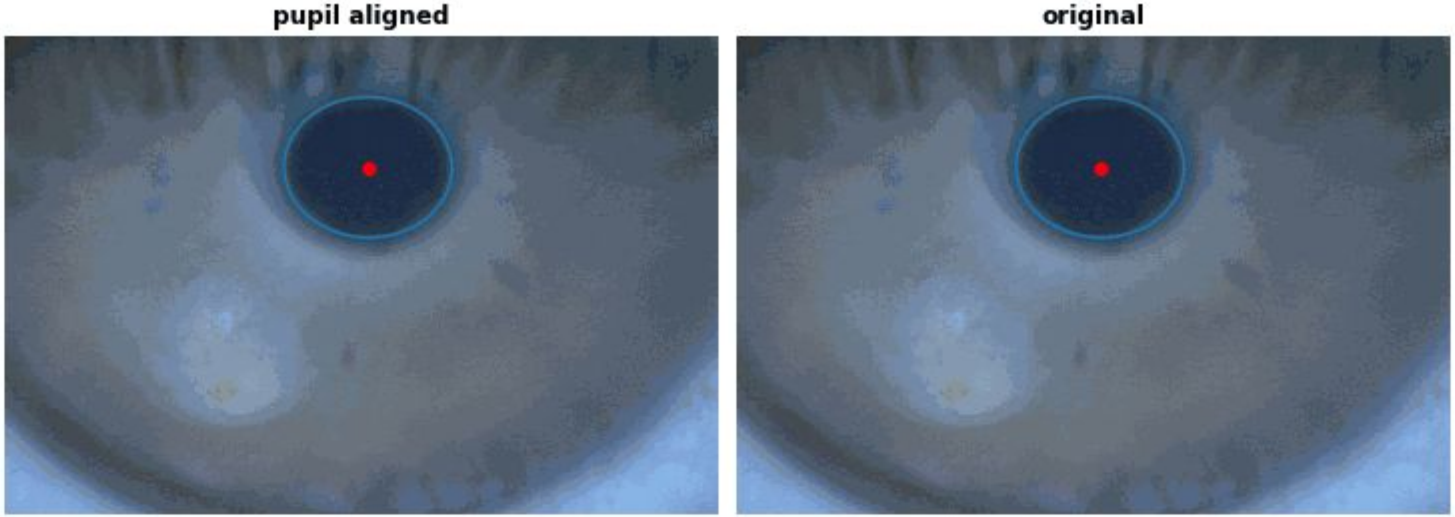


original

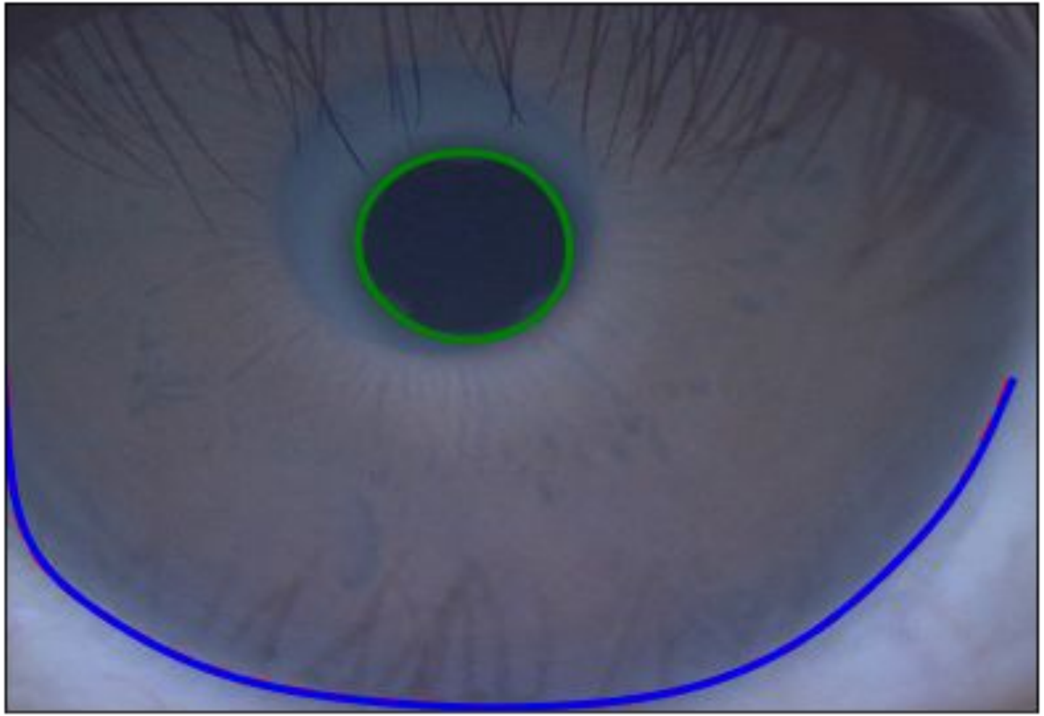



pupil aligned
original


pupil aligned
original


pupil aligned
original

Iris Segmentation



Lipid Layer Visual Enhancement

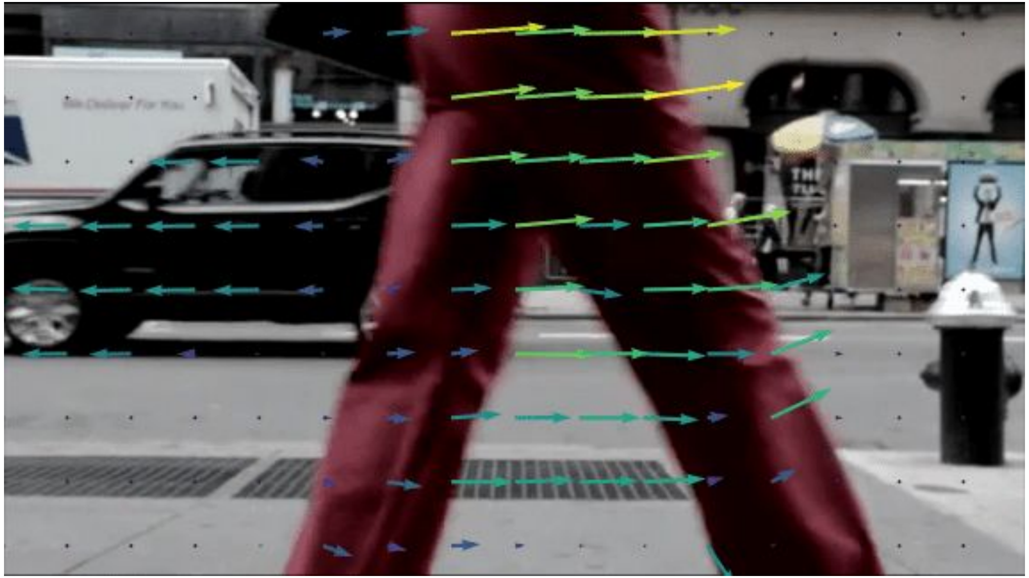
Original | Sharpened | Frequency Filtering | Average Frame Subtraction | Local Histogram Equalization

Tracking with Optical Flow

Optical Flow Assumptions

Optical flow works on several assumptions:

1. The pixel intensities of an object do not change between consecutive frames.
2. Neighbouring pixels have similar motion.



Optical Flow Equation

$$I(x, y, t) = I(x + \Delta x, y + \Delta y, t + \Delta t)$$

$$I(x + \Delta x, y + \Delta y, t + \Delta t) = I(x, y, t) + \frac{\partial I}{\partial x}\Delta x + \frac{\partial I}{\partial y}\Delta y + \frac{\partial I}{\partial t}\Delta t + \text{higher-order terms}$$

$$\frac{\partial I}{\partial x}V_x + \frac{\partial I}{\partial y}V_y + \frac{\partial I}{\partial t} = 0$$

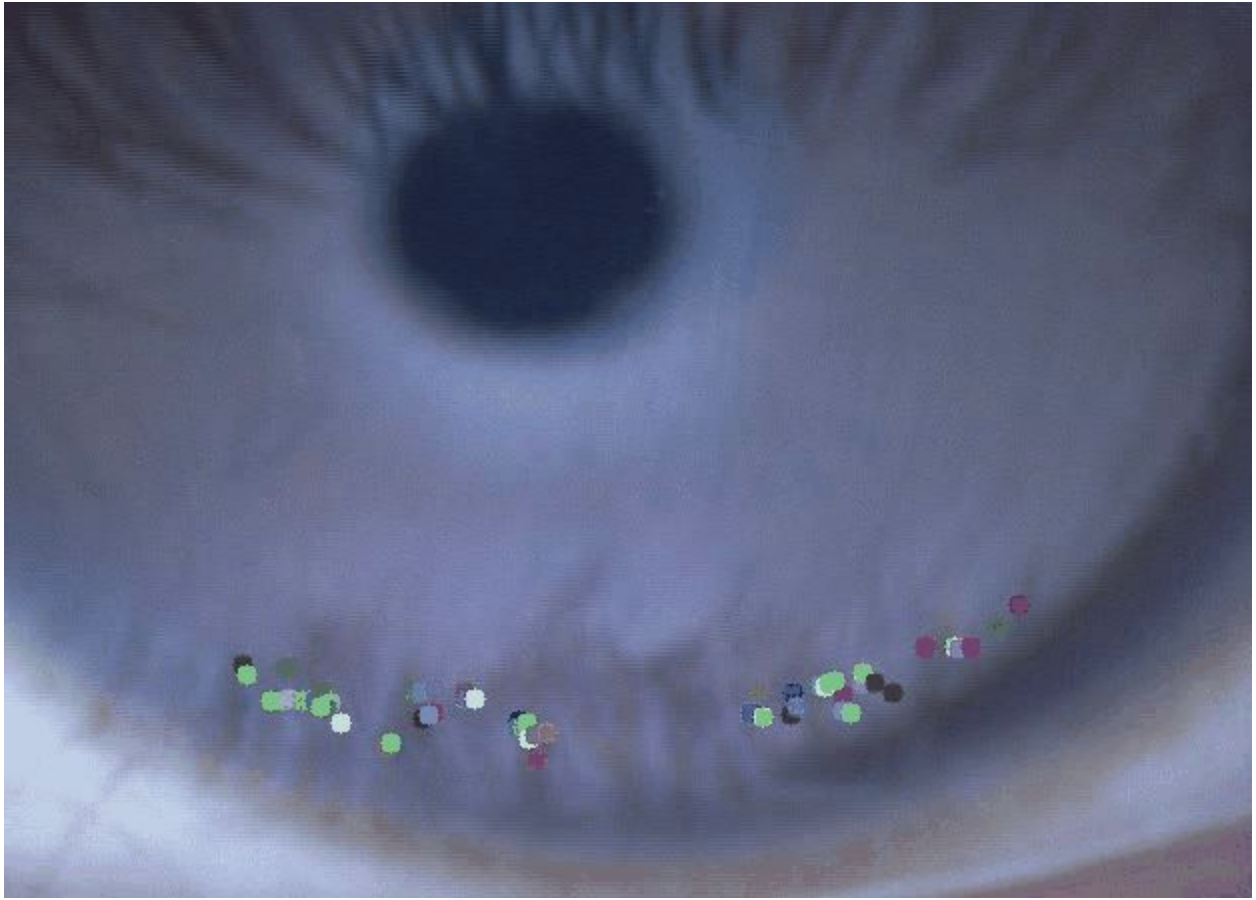
Lucas-Kanade Method

$$u = \frac{dx}{dt} \; ; \; v = \frac{dy}{dt}$$

Lucas-Kanade method takes a 3x3 patch around the point. So all the 9 points have the same motion. This yields 9 equations and two unknowns.

$$\begin{bmatrix} u \\ v \end{bmatrix} = \begin{bmatrix} \sum_i f_{x_i}{}^2 & \sum_i f_{x_i} f_{y_i} \\ \sum_i f_{x_i} f_{y_i} & \sum_i f_{y_i}{}^2 \end{bmatrix}^{-1} \begin{bmatrix} -\sum_i f_{x_i} f_{t_i} \\ -\sum_i f_{y_i} f_{t_i} \end{bmatrix}$$

Tracking Demonstration



Tracking Demonstration

Tracking Demonstration (cont.)

Tracking Demonstration (cont.)

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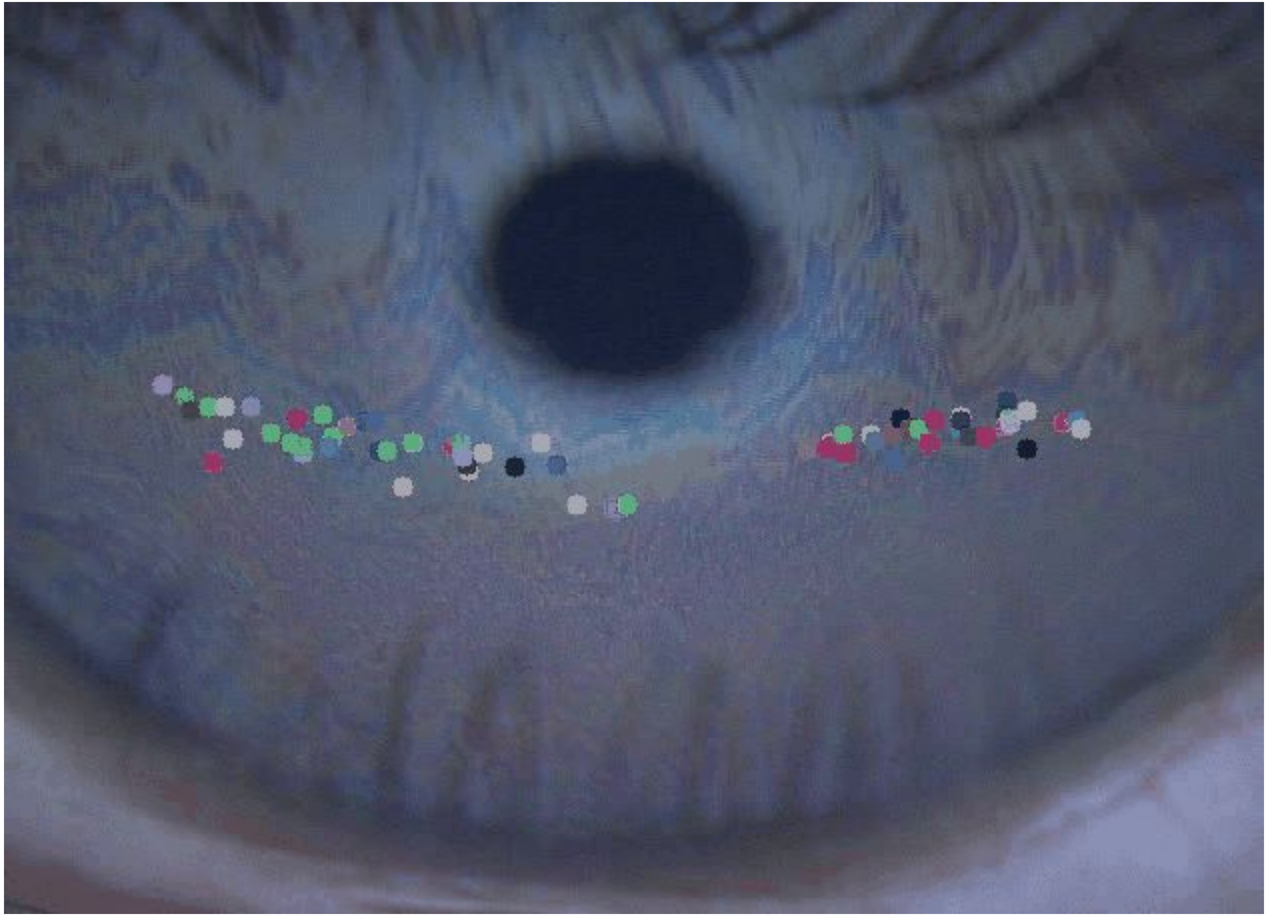

Tracking Demonstration (cont.)

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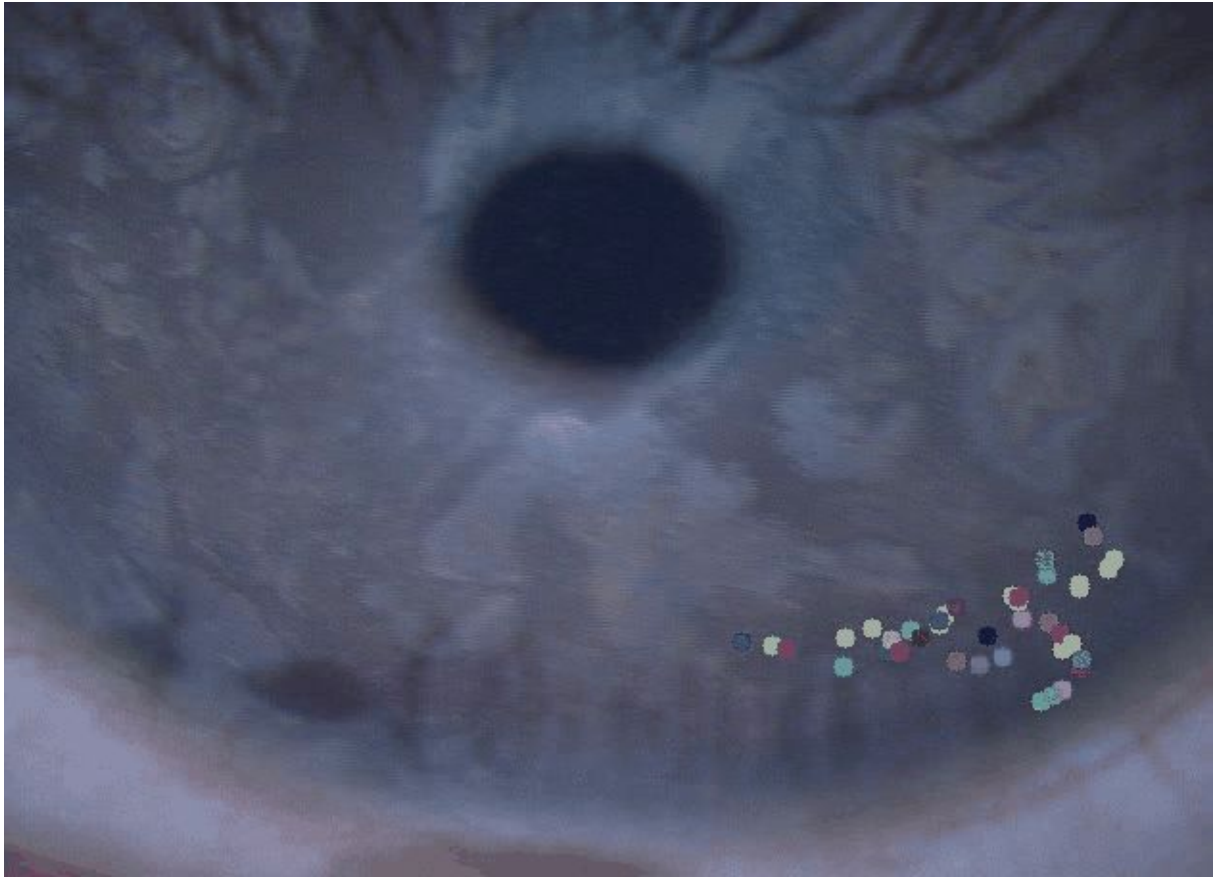
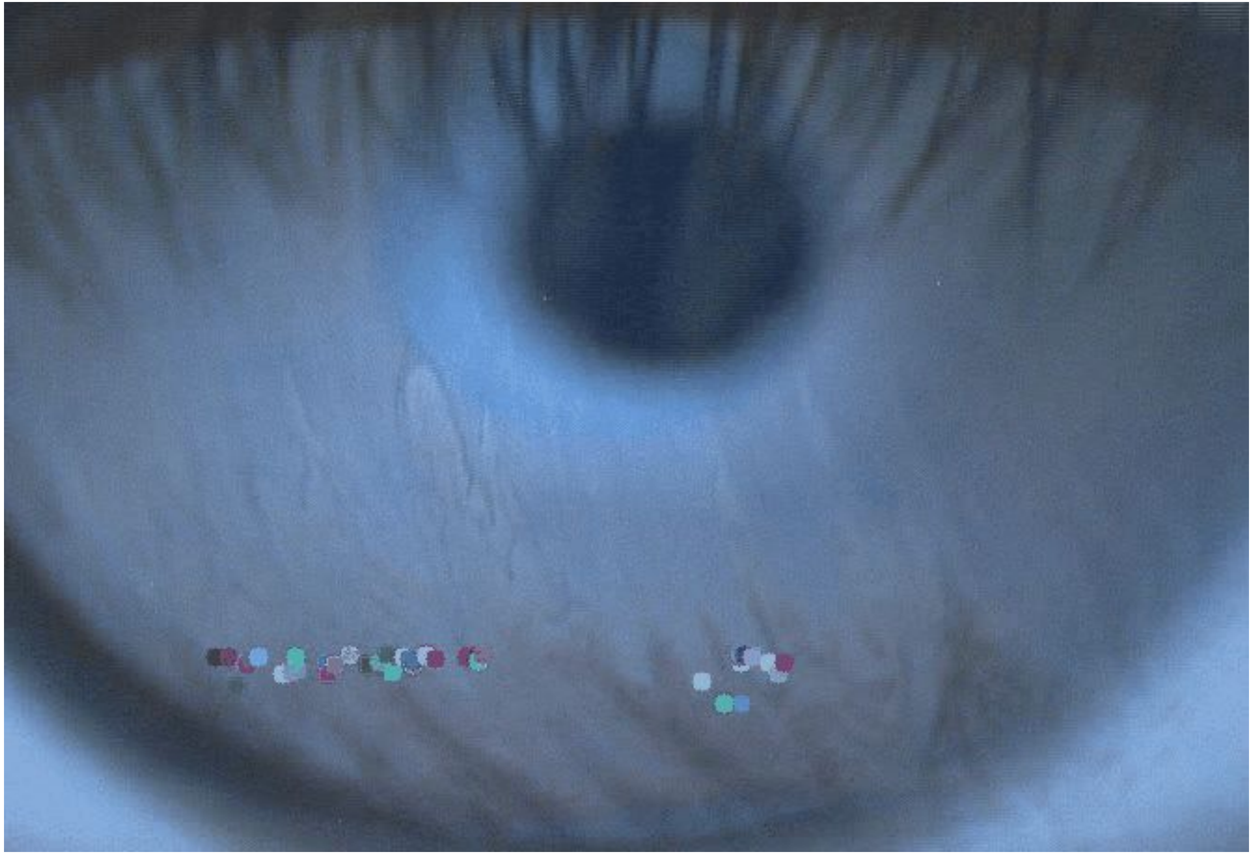
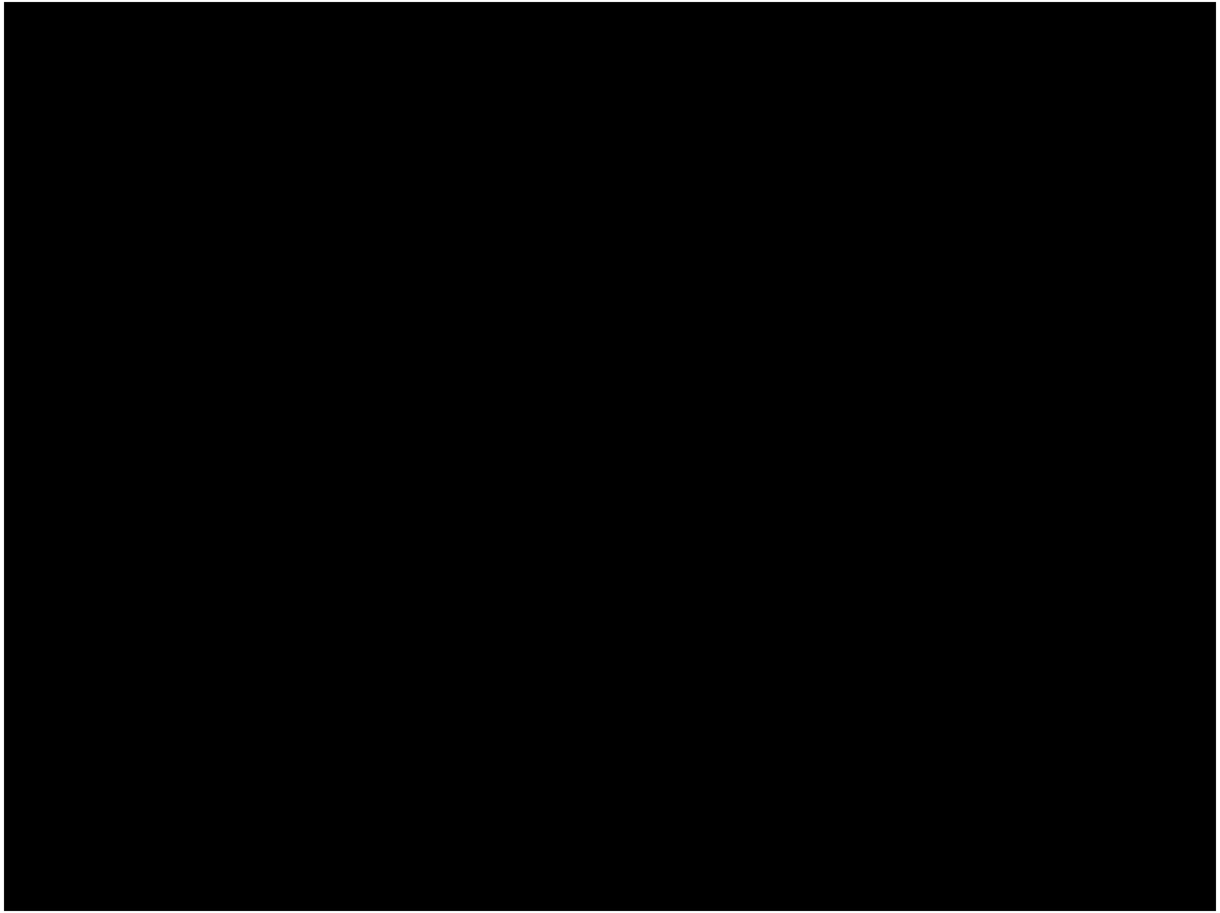


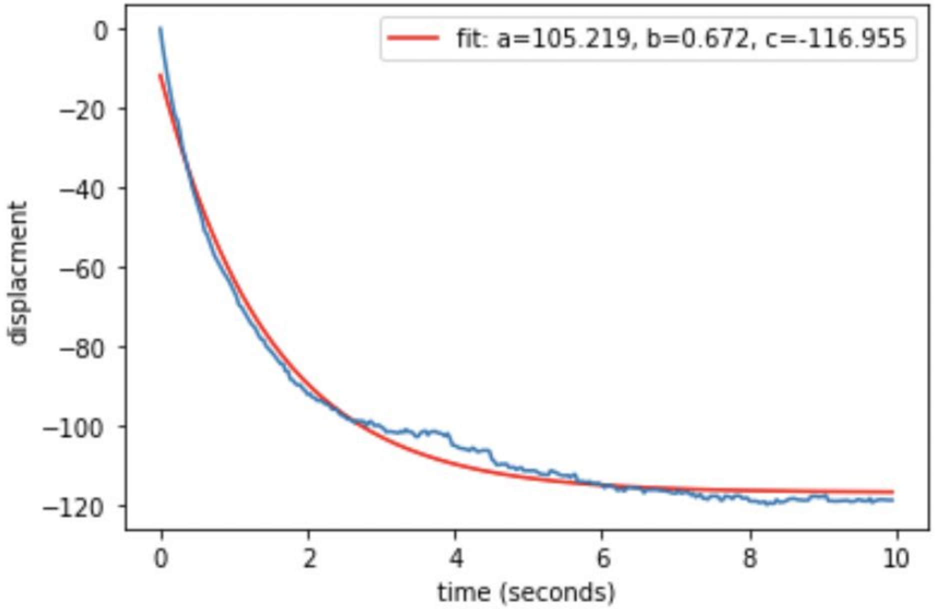
Tracking Demonstration (without stabilization)



Dense Optical Flow (Farneback's Algorithm)



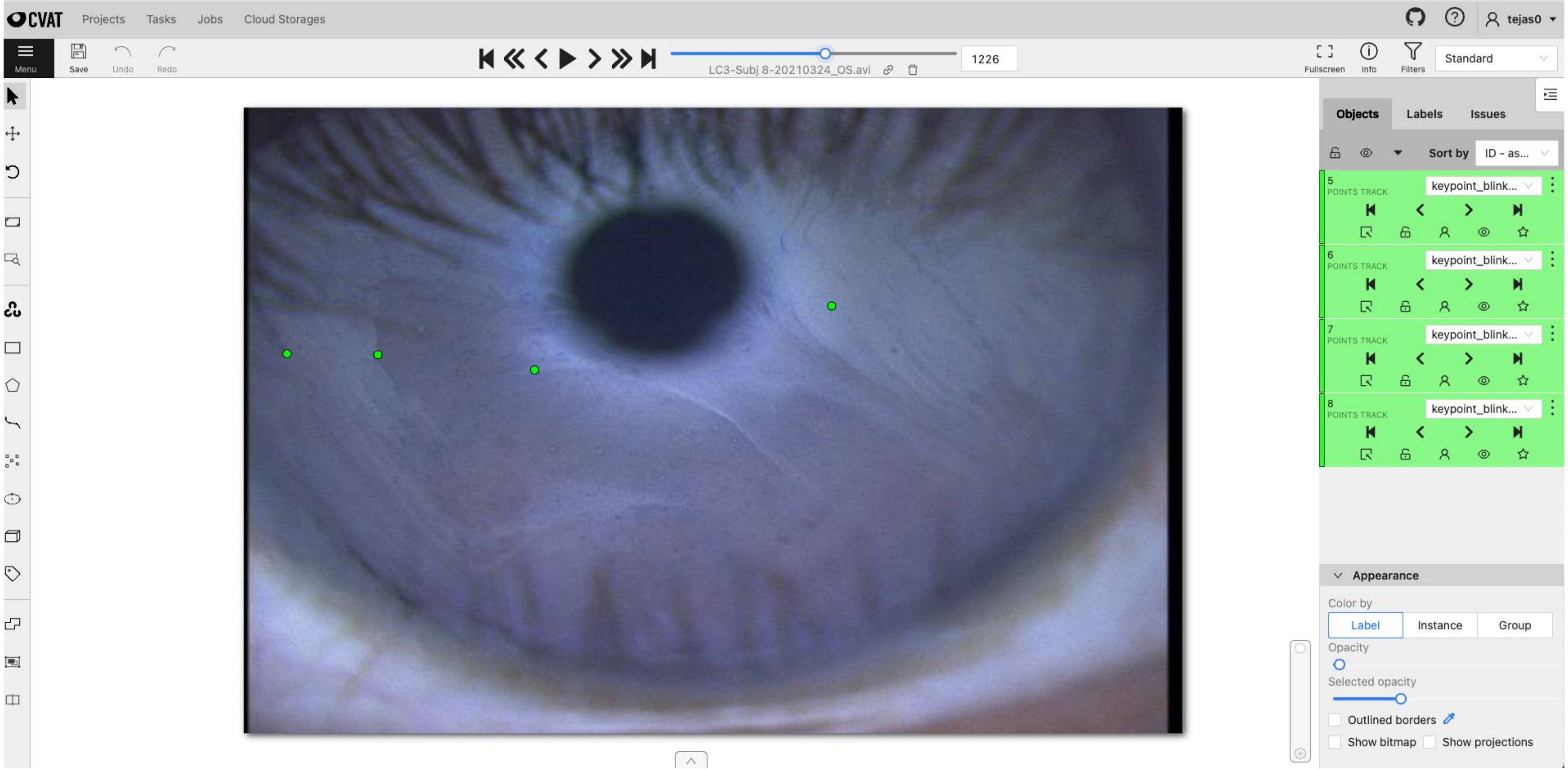
Y-Displacement vs Time




```
displacement = 105.2194947755335 * e^(-0.671622542657137 * time) + -116.95488456474348
characteristic time: 1.4889315597473916
```

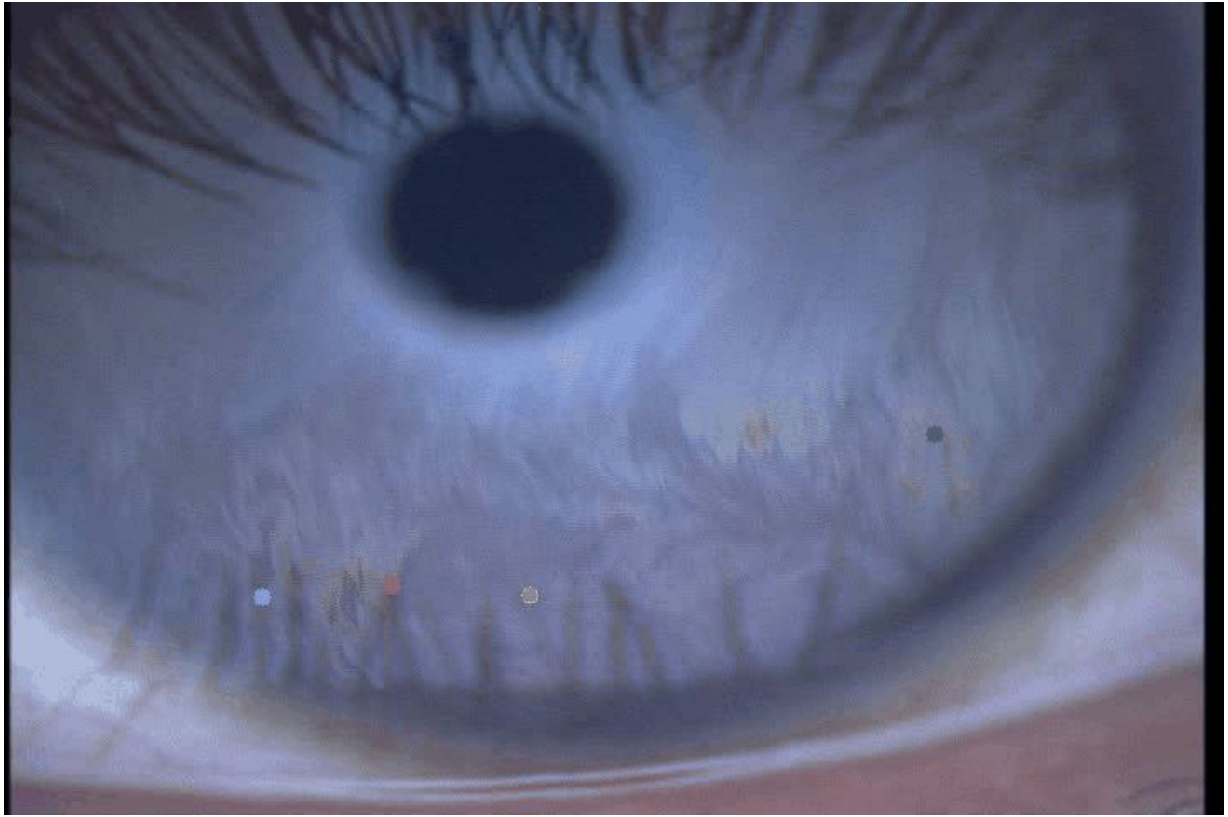
Results

Annotations

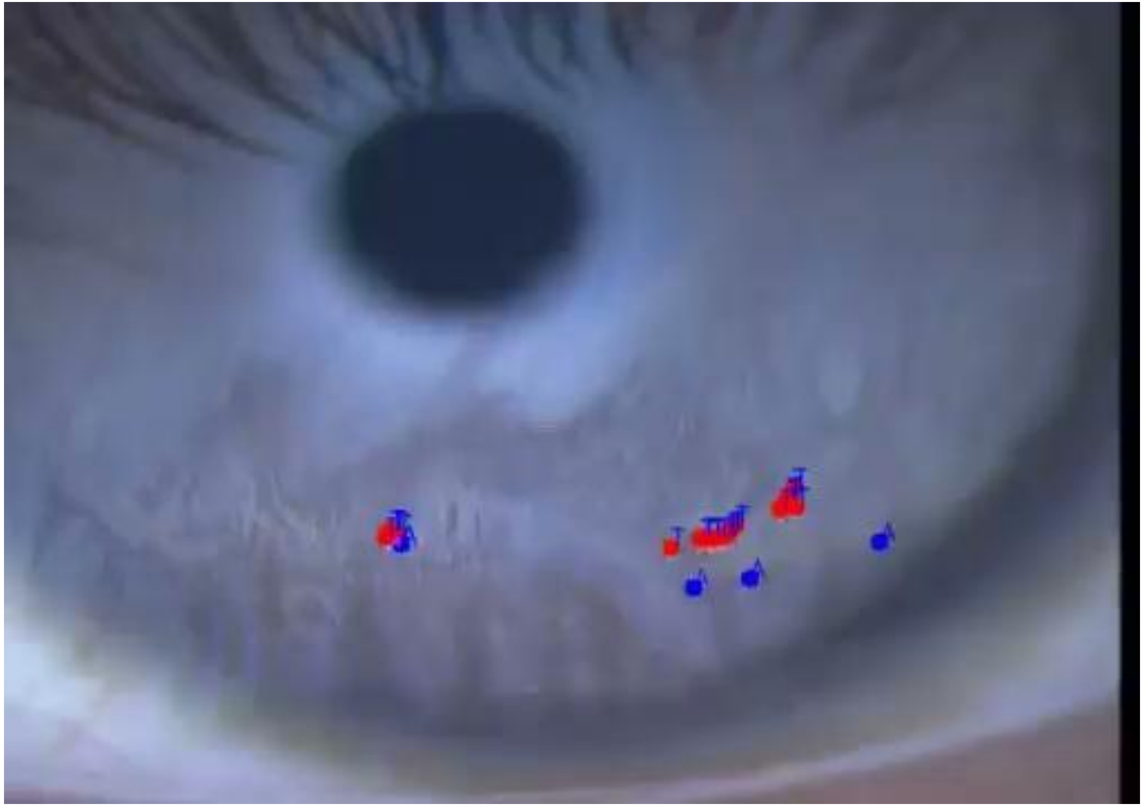


Annotation Visualization

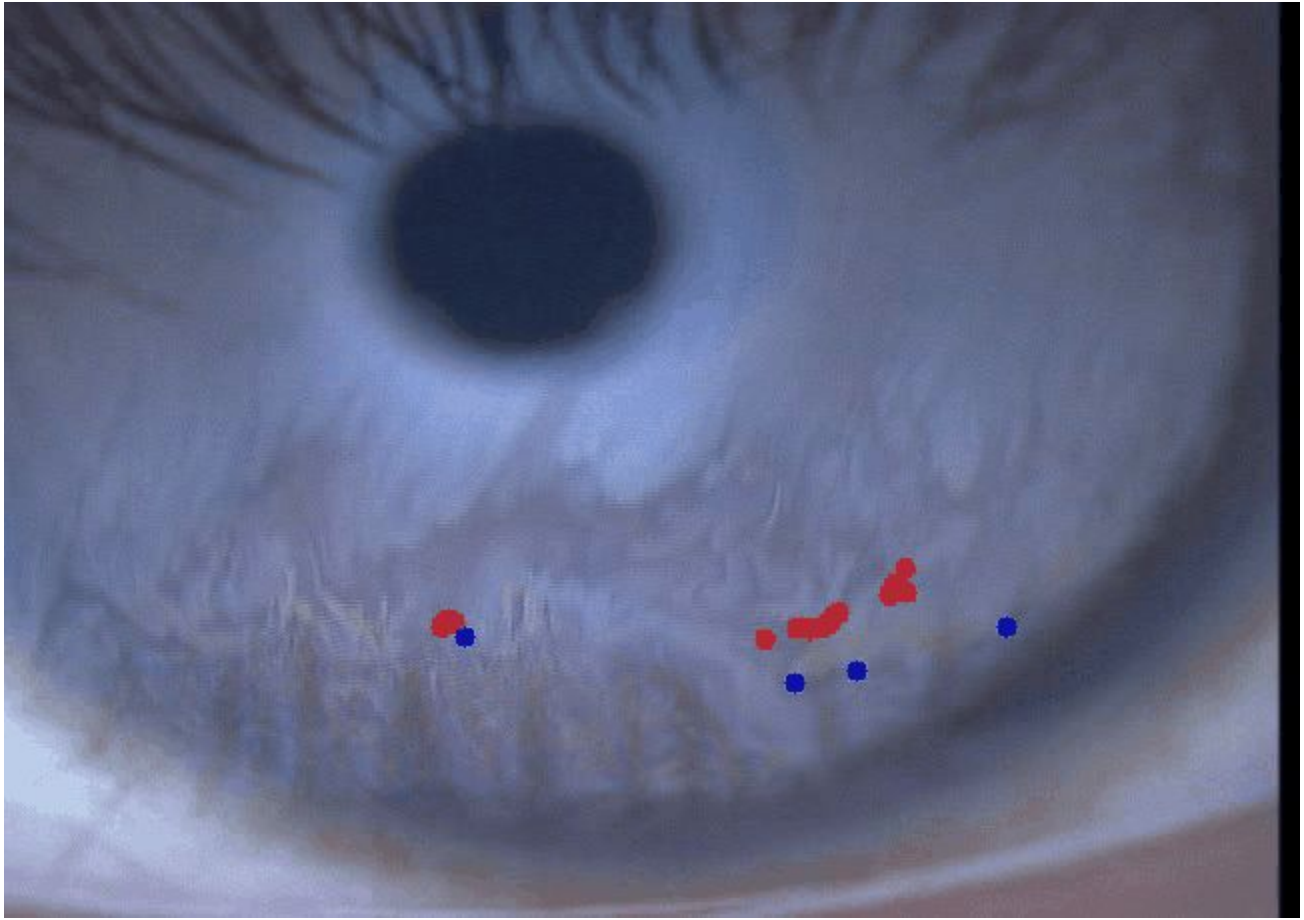
Annotation Visualization



Annotations Compared to Tracking Method



Annotations Compared to Tracking Method



Validating the Tracking Method

Table 1: Computed Characteristic Times versus Annotation Characteristic Times

Computed y displacement λ	Annotation y displacement λ	Computed x displacement λ	Annotation x displacement λ
0.59	0.46	0.66	0.8
2.58	1.78	7.57	8.94
2.52	1.91	2.47	3.16
0.79	0.53	28.98	3.12
1.39	6.58	2.32	1.62

Relation to OSDI and TLL Thinning

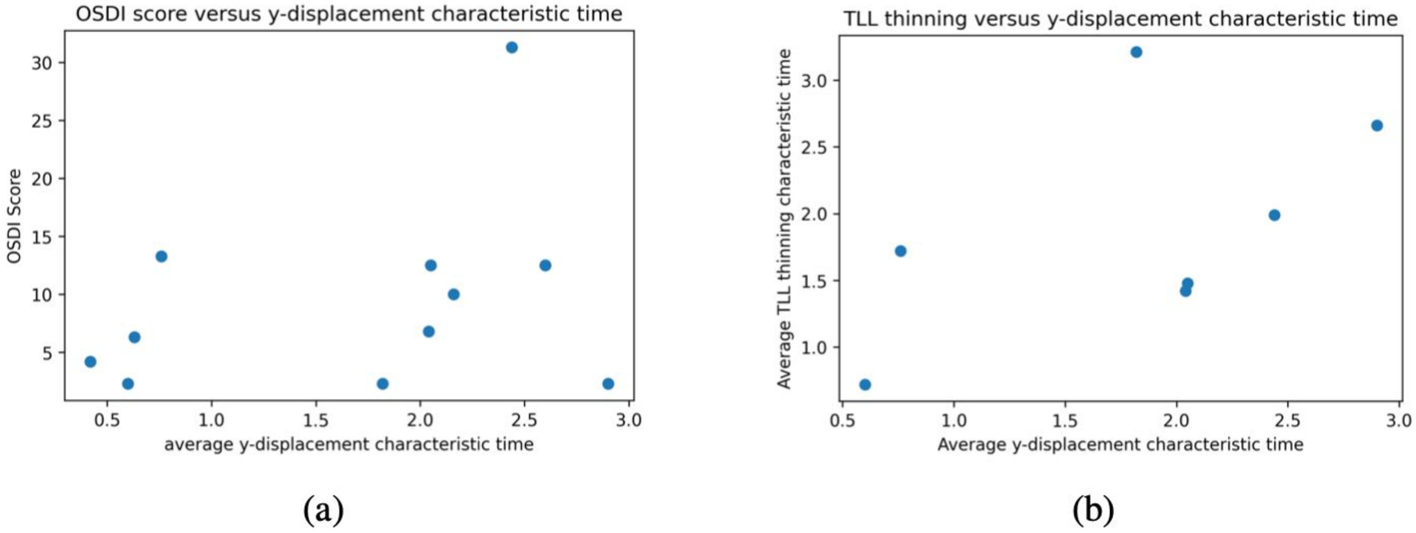


Figure 2

What’s Next?

Tear Film Lipid Layer Thickness

Calculating Thickness from Image [3]

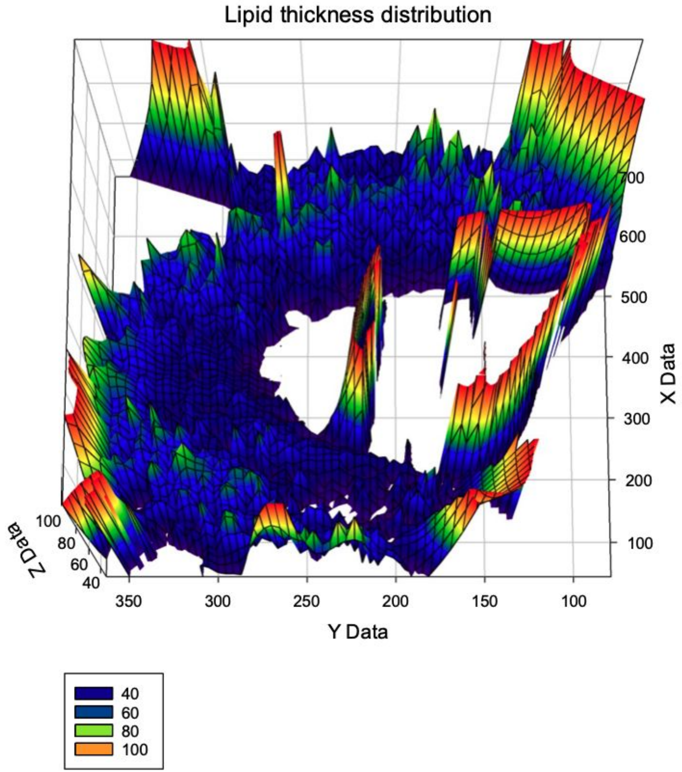
[3] Hyeonha Hwang et al. *Image-based quantitative analysis of tear film lipid layer thickness for meibomian gland evaluation*

$$\text{Red}(d) = \sum_{\lambda} I_{\text{INT}}(\lambda, d) \cdot R_{\text{STDOBS}}(\lambda), \tag{12}$$

$$\text{Green}(d) = \sum_{\lambda} I_{\text{INT}}(\lambda, d) \cdot G_{\text{STDOBS}}(\lambda), \tag{13}$$

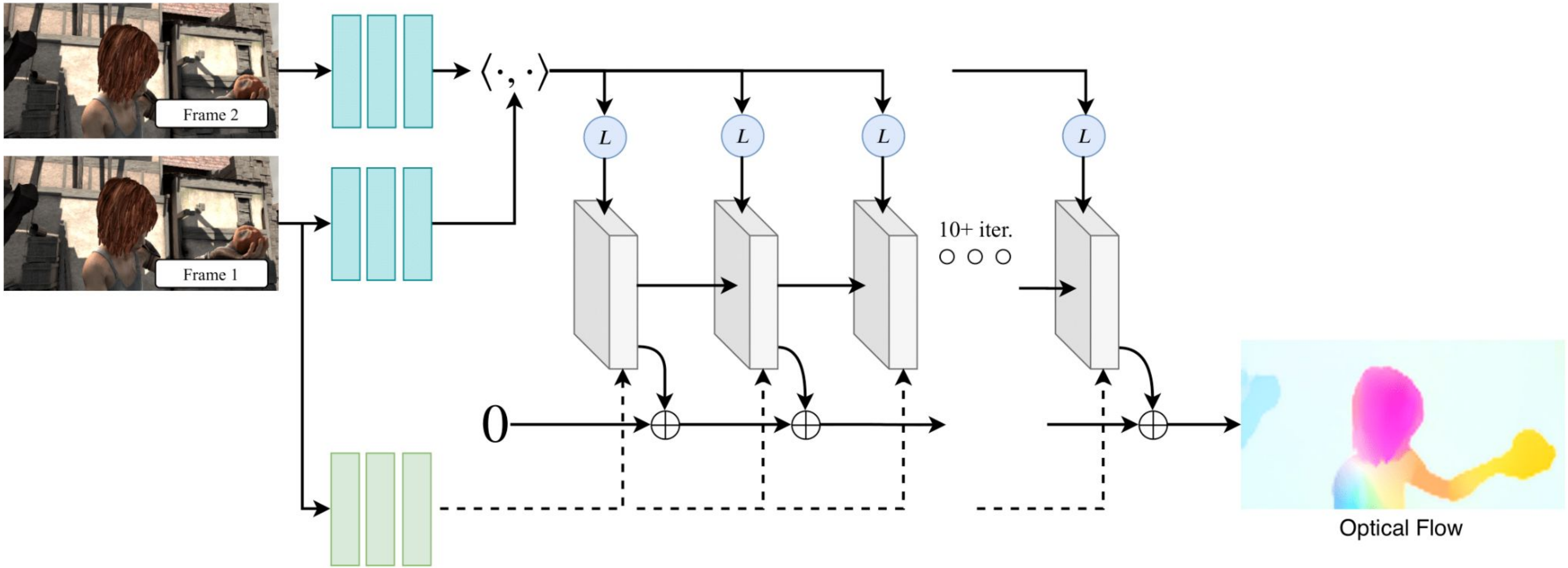
$$\text{Blue}(d) = \sum_{\lambda} I_{\text{INT}}(\lambda, d) \cdot B_{\text{STDOBS}}(\lambda). \tag{14}$$

Calculating Thickness from Image (cont.)



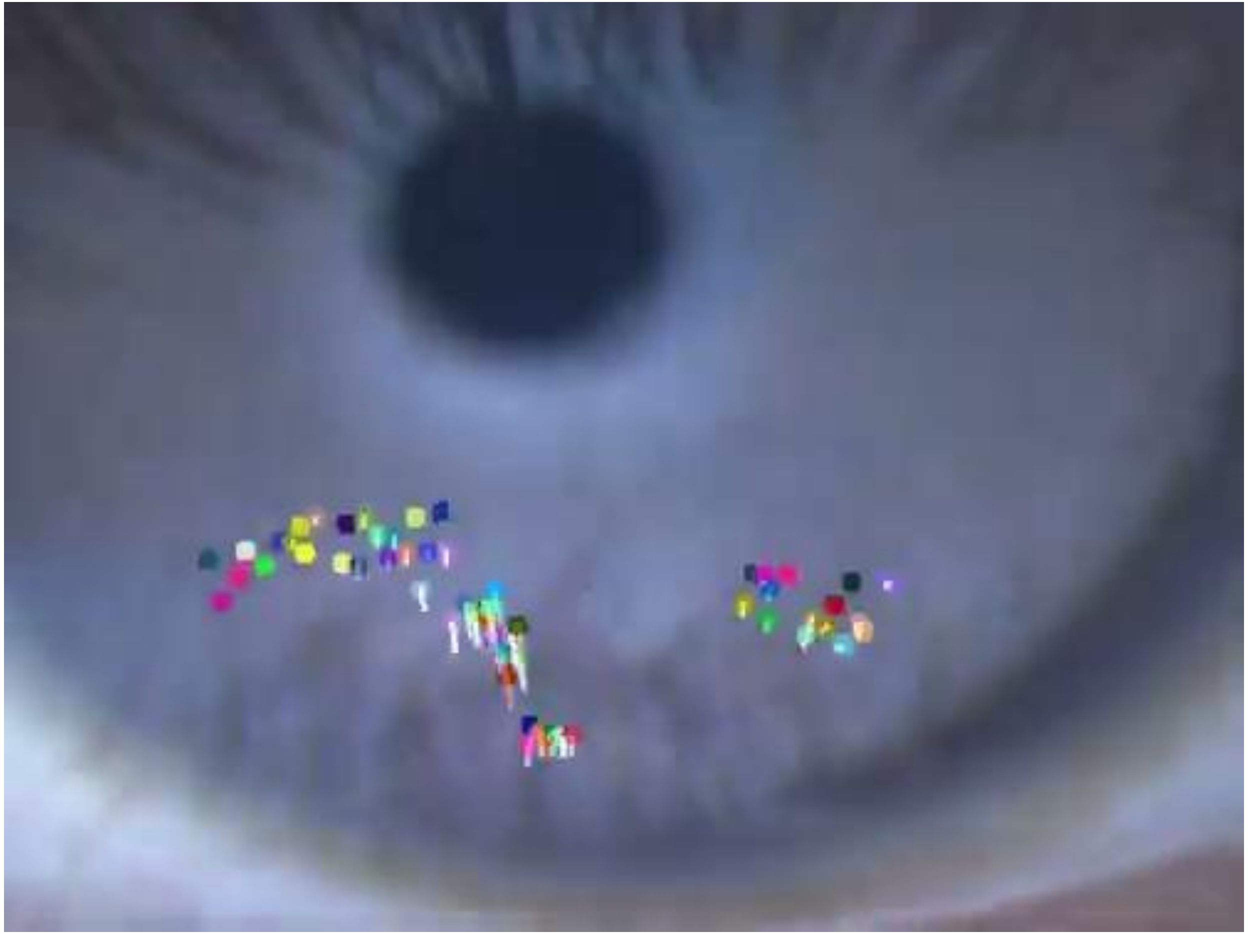
Neural Networks?

RAFT: Recurrent All-Pairs Field Transforms for Optical Flow

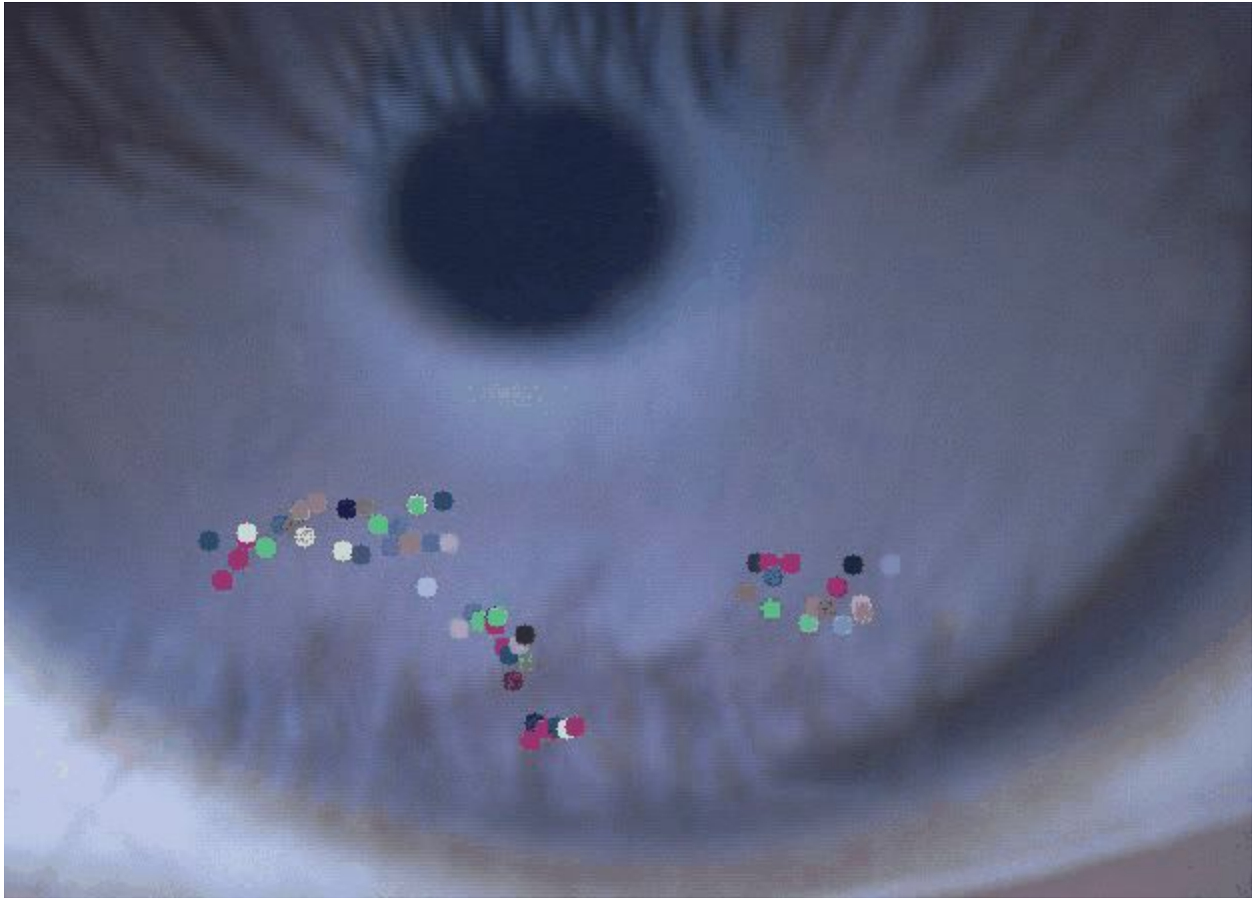


RAFT Baseline for Lipid Layer Tracking

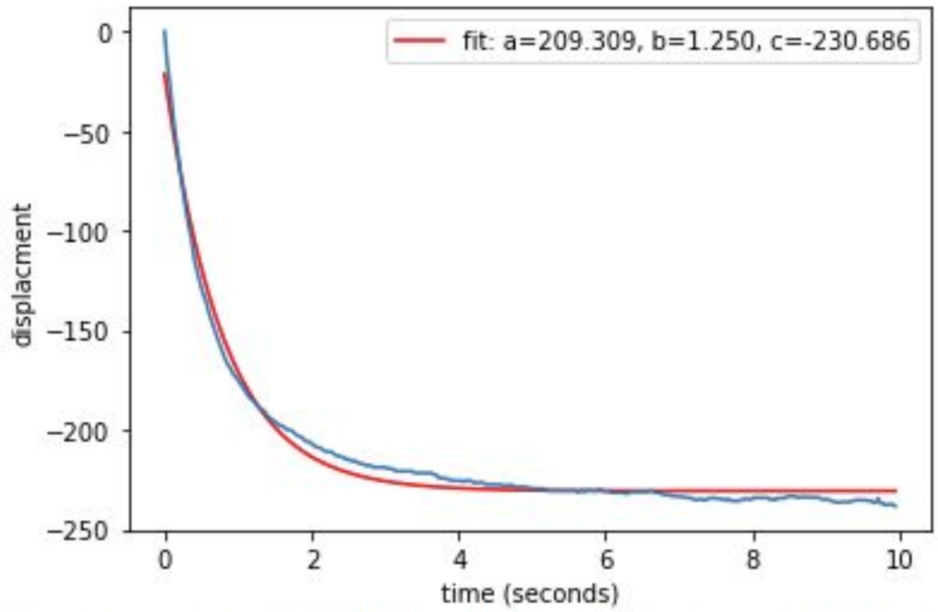
RAFT Baseline for Lipid Layer Tracking (cont.)



RAFT Baseline for Lipid Layer Tracking (cont.)



RAFT Baseline for Lipid Layer Tracking (cont.)




```
displacement = 209.3089132660783 * e^(-1.2501360041699203 * time) + -230.6861017507681
characteristic time: 0.7999129668007534
```

Our Website (under construction)

Upload video to start tear film analysis

UPLOAD

OS4-427_3221-OD2-TLL-06222022.avi

This is a sample description

https://easytear-dev.github.io/

Questions?