Tracking the Dynamics of the Tear Film Lipid Layer

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My Amazing Collaborators

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Tear Film Lipid Layer Visualized
Tear Film Lipid Layer Visualized (cont.)
Tear Film Diagram

- Lipid Layer
- Secretory Mucus Layer
- Epithelium
- Cornea
- Stroma
- Non-polar
- Polar Aqueous
- Conjunctival Goblet Cells
- Muc5AC
- MAM (MUC16)
Prior Work in Lipid Layer Motion Tracking

Prior Work Conclusions

- In all cases, the time-dependent changes in TFFL spread could be described by the expression $H(t) - H(0) = \rho [1 - \exp(t/\lambda)]$, where $H(t)$ is the averaged height in millimeters at time $t$, $H(0)$ is the averaged height at $t = 0$, $\rho$ is a constant, $t$ is time in seconds, and $\lambda$ 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]

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

Input Video
- Blink Detection
- Video Stabilization
- Iris Segmentation
- Lipid Layer Visual Enhancement
- Optical Flow
- Visual Tracking Metrics
Preprocessing
Blink Detection

- Blink Frame
- Inter-Blink Frame
Blink Detection (cont.)
Video Stabilization with Pupil Tracking [2]

Iris Segmentation
## Lipid Layer Visual Enhancement

<table>
<thead>
<tr>
<th>Original</th>
<th>Sharpened</th>
<th>Frequency Filtering</th>
<th>Average Frame Subtraction</th>
<th>Local Histogram Equalization</th>
</tr>
</thead>
</table>

![Image of Lipid Layer Visual Enhancement](image-url)
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

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.

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

\[
u = \frac{dx}{dt}; \quad v = \frac{dy}{dt}
\]
Tracking Demonstration
Tracking Demonstration
Tracking Demonstration (cont.)
Tracking Demonstration (cont.)
Tracking Demonstration (cont.)
Tracking Demonstration (cont.)
Tracking Demonstration (without stabilization)
Dense Optical Flow (Farneback's Algorithm)
Y-Displacement vs Time

\[
displacement = 105.2194947755335 \times e^{(-0.671622542657137 \times time)} + -116.95488456474348
\]

characteristic time: 1.4889315597473916
Results
Annotation Visualization
Annotation Visualization
Annotations Compared to Tracking Method
Annotations Compared to Tracking Method
Validating the Tracking Method

<table>
<thead>
<tr>
<th>Computed $y$ displacement $\lambda$</th>
<th>Annotation $y$ displacement $\lambda$</th>
<th>Computed $x$ displacement $\lambda$</th>
<th>Annotation $x$ displacement $\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.59</td>
<td>0.46</td>
<td>0.66</td>
<td>0.8</td>
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<tr>
<td>2.58</td>
<td>1.78</td>
<td>7.57</td>
<td>8.94</td>
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<td>2.52</td>
<td>1.91</td>
<td>2.47</td>
<td>3.16</td>
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<tr>
<td>0.79</td>
<td>0.53</td>
<td>28.98</td>
<td>3.12</td>
</tr>
<tr>
<td>1.39</td>
<td>6.58</td>
<td>2.32</td>
<td>1.62</td>
</tr>
</tbody>
</table>
Relation to OSDI and TLL Thinning

(a) OSI score versus y-displacement characteristic time

(b) TLL thinning versus y-displacement characteristic time

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*

\[
\text{Red}(d) = \sum_{\lambda} I_{\text{INT}}(\lambda, d) \cdot R_{\text{STDOBS}}(\lambda),
\]

(12)

\[
\text{Green}(d) = \sum_{\lambda} I_{\text{INT}}(\lambda, d) \cdot G_{\text{STDOBS}}(\lambda),
\]

(13)

\[
\text{Blue}(d) = \sum_{\lambda} I_{\text{INT}}(\lambda, d) \cdot B_{\text{STDOBS}}(\lambda).
\]

(14)
Calculating Thickness from Image (cont.)

Lipid thickness distribution

40 60 80 100
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.)

\[
\text{displacement} = 209.3089132660783 \times e^{(-1.2501360041699203 \times \text{time})} + -230.6861017507681
\]

characteristic time: 0.7999129668007534
Our Website (under construction)

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