



# PreLens Tear Film Segmentation and Reconstruction in Interferometry Images

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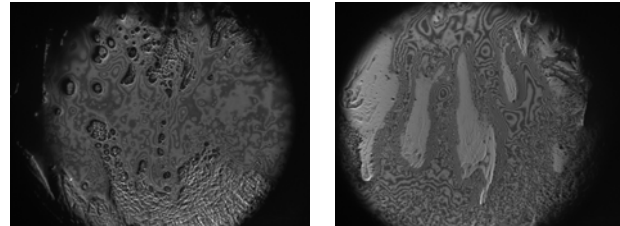
## Objective

This study was conducted to segment and reconstruct the surface of the preLens tear film layer from interferometry images. This will prove useful in the evaluation of treatments for dry eye problems and in modeling tear film fluid dynamics.

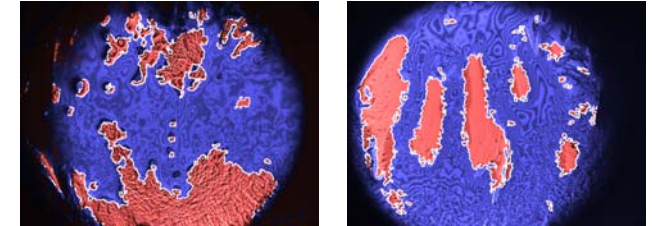
## Methods

- Preprocessing
  - Image normalization with 2D Hilbert transform to suppress slow background and modulation variation
  - Video stabilization with filtered optical flow to remove high frequency saccadic eye motion
- Segmentation
  - Texture feature extraction using a bank of Gabor filters
  - Classification with resilient subclass discriminant analysis method to separate dry areas from wet areas as the referenced zero thickness region
- Phase demodulation
  - Valley and ridge line extraction to solve sign ambiguity
  - Graph cuts to solve  $2\pi$  ambiguity

## PreLens Tear Film Interferometry Images



## Segmentation

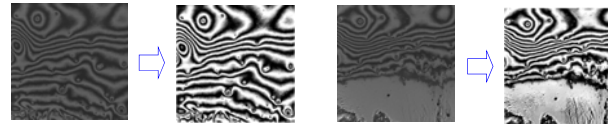


$$h(x, y) = g(x', y') \exp[j2\pi(Ux + Vy)]$$

$$g(x, y) = \exp(-\frac{1}{2}((x/s_x)^2 + (y/s_y)^2)) / (2\pi s_x s_y)$$

$$(x', y') = (x \cos \theta + y \sin \theta, -x \sin \theta + y \cos \theta)$$

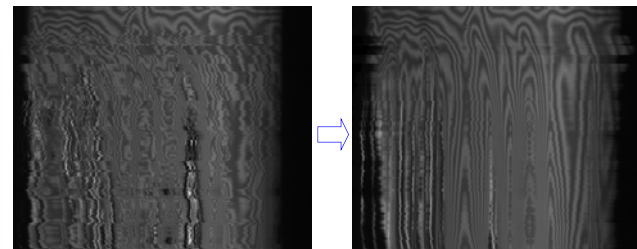
## Normalization



$$I(x, y) = a(x, y) + b(x, y) \cos(\phi(x, y)) \quad I'(x, y) = b(x, y) \cos(\phi(x, y))$$

$$\cos(\phi(x, y)) = I' / \sqrt{I^2 + |F^{-1}[(iu + iv)F(I') / \sqrt{u^2 + v^2}]|^2}$$

## Motion Stabilization



$$E(u, v) = \iiint_{x, y, t} |I(x+u, y+v, t+1) - I(x, y, t)|^2 dx dy dt$$

$$+ \gamma \iiint_{x, y, t} |\nabla I(x+u, y+v, t+1) - \nabla I(x, y, t)|^2 dx dy dt$$

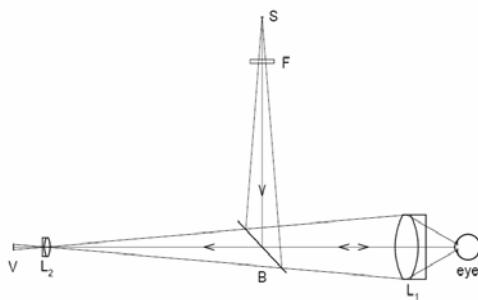
$$+ \alpha \iiint_{x, y, t} |u_x + u_y + u_t|^2 + |v_x + v_y + v_t|^2 dx dy dt$$

$$[u, v] = [u(x, y, t), v(x, y, t)] = \arg \min_{u, v} E(u, v)$$

$$u(x, y, t) = \hat{u}(x, y, t) + u_c(t)$$

$$v(x, y, t) = \hat{v}(x, y, t) + v_c(t)$$

## Interferometric Imaging



A simplified diagram of the tear film imaging system, a modified Doane's interferometer

## Surface Reconstruction

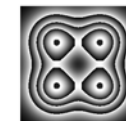
A synthetic example



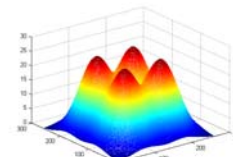
$$\cos(\phi(x, y))$$



$$\text{sign}(\sin(\phi(x, y)))$$



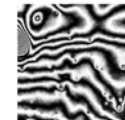
$$\phi(x, y)$$



$$\phi(x, y)$$

$$\phi(x, y) = \phi(x, y) - 2k\pi \quad |\phi(x, y)| \leq \pi$$

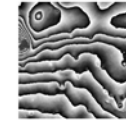
Real PLTF subimage



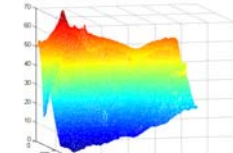
$$\cos(\phi(x, y))$$



$$\text{sign}(\sin(\phi(x, y)))$$



$$\text{wrap}(\phi(x, y))$$



$$\phi(x, y)$$

$$E(k) = \sum_{i, j \in I} V(\Delta \phi_{i, j}^h) h_{i, j} + V(\Delta \phi_{i, j}^v) v_{i, j}$$

$$\Delta \phi_{i, j}^h = [2\pi(k_{i, j} - k_{i, j-1}) + \Delta \phi_{i, j}^h]; \Delta \phi_{i, j}^v = [2\pi(k_{i, j} - k_{i-1, j}) + \Delta \phi_{i, j}^v]$$

$$\Delta \phi_{i, j}^h = \phi_{i, j} - \phi_{i, j-1}; \Delta \phi_{i, j}^v = \phi_{i, j} - \phi_{i-1, j}$$