TAMPERE UNIVERSITY OF TECHNOLOGY

Fiber Photogrammetry

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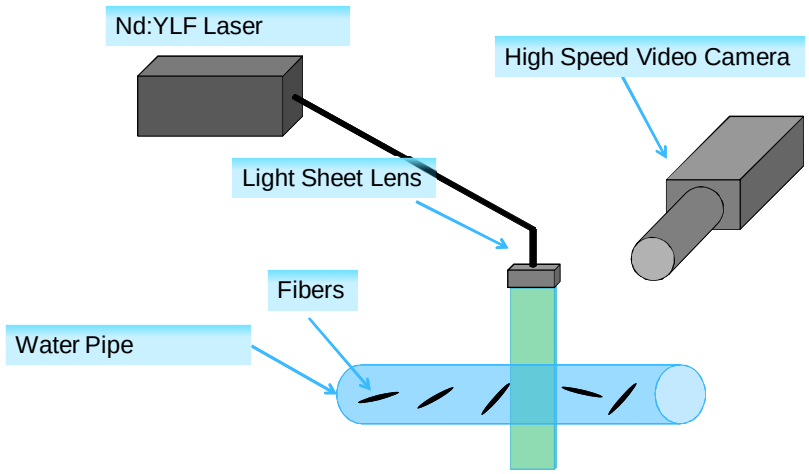
Experimental Setup

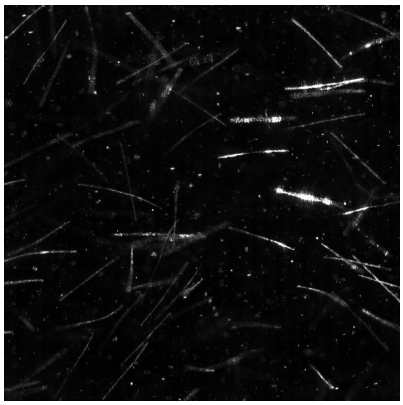


Experimental Setup

- The camera used was Photron SA-5 with 16GB memory.
- Framerate of 2000-4000 fps was observed adequate depending on imaging region and flow-rate. This produced 1000 px x 1000 px resolution.
- Fiber dimensions were 1092 µm x 23.3 µm.
- Different Infinity K2/SC lens configurations were tested for fiber imaging.

K2 Inifinity CF-4 Lens

- CF-4 lens is the CF series lens with largest zoom.
- Fibers are clearly visible, but the intensity range differs greatly.
- They may be partially blurred.

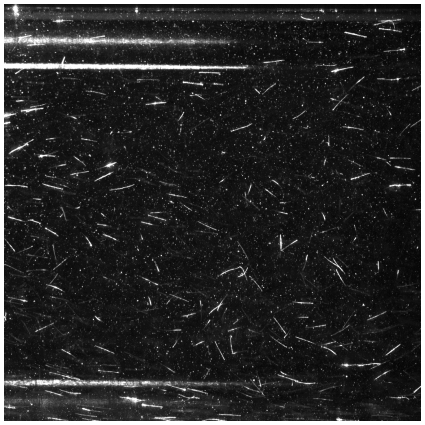


K2 Inifinity CF-3 Lens

- Very similar to CF-4, but slightly less zoom.
- Also show partial blurring of fibers.
- Imaging region is app. 0.6 cm x 0.6 cm.

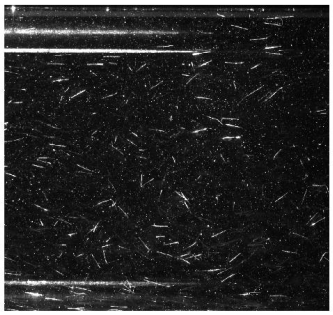
K2 Infinity STD lens

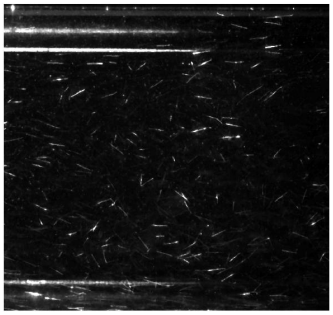
- Fibers are almost in DOF.
- Imaging region is almost the same size as the pipe diameter (2 cm).



Extracting Fibers from Image

- Tracer particles can be excluded from the image by simple median filter.





Detection of Fibers

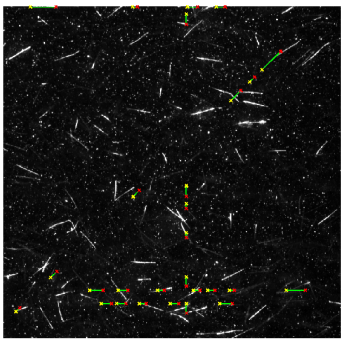
- Classical Hough transform (Radon trasform)
- Convolution with elongated gaussian profile or ”Mexican Hat”, etc.
- Steerable filter based ridge detectors.

Hough Transform

- Requires fibers to be straight, and relatively elongated (not satisfied by the data sets).
- Initial performance in the recorded data sets were poor.
- Relatively fast, and fiber orientations and lengths are ”easily” obtained.

Hough Transform: Example

- Lines are located in false recognitions, and recognition rate was low.
- Use of ridge detector instead of edge detector might improve performance.



Direct Convolution (DC)

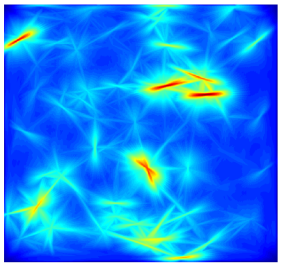
- Based on computing image convolution with kernel *h*.
- *h* was chosen as gaussian function with nonisotropic covariance $h = \exp(-x^T \Sigma^{-1} x)$.
- Since Σ is symmetric positive definite it can be decomposed using Schur decomposion: $\Sigma = R(\theta)^T D R(\theta)$, where *D* encodes the shape information, and θ orientation.

Direct Convolution

- Once suitable kernel *h* is constructed, convolution map can be computed by: $C(x, y, \theta) = I * h_\theta(x, y)$.
- Fibers show themselves as peaks in the *C* map, and orientation is found by choosing the angle that maximizes local *C*.
- Computationally expensive since every orientation requires one 2D-convolution.

Direct Convolution: Example

- Convolution of a sample image. 80 different orientations were computed, and maximal convolution value was plotted.



Steerable Filters (SF)

- Based on similar idea as ”direct convolution”.
- Unlike in the DC case, the kernel is chosen such that it different orientations can be presented by following linear combination:

$$I * h_\theta(x,y) = \sum_{k,i} b_{k,i}(\theta) I * \left(\frac{\partial^{k-i}}{\partial x^{k-i}} \frac{\partial^i}{\partial y^i} g(x,y) \right).$$

Angle dependent part

Angle independent part

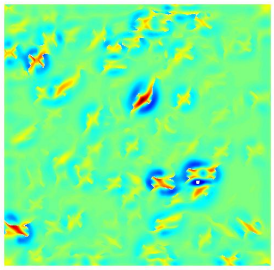
Steerable Filters

- Canny ridge detector can be implemented as steerable filter, where *g(x,y)* is chosen as isotropic gaussian distribution.
- Convolution kernel *h* is then given by:

$$h(x,y) = -\sqrt{\frac{3}{4\pi}}\sigma\left(\frac{\partial^2 g}{\partial x^2} + \frac{1}{3}\frac{\partial^2 g}{\partial y^2}\right),$$
$$h_\theta(x,y) = h(R(\theta)[x,y]^T).$$

Steerable Filters: Example

- Convolution of a sample image by ridge detector. Maximal convolution value was plotted.



Steerable Filters

- Convolution values at fibers are larger, but there are no clear peaks middle of a fiber, since SF is a ridge detector.
- Positions need to be computed by averaging, which can be difficult for overlapping fibers.
- Orientation data can be used as base for clustering.

Steerable Filter vs DC

- SF is *O(1)* respect to angular resolution, while DC *O(M)*, where *M* is number of orientations.
- If image has *N* pixels both methods are *O(NlogN)* (in case FFT is used for 2D convolutions).

Steerable Filter vs DC

- Since there are less possible fiber positions in the DC (in perfect world only one) the clustering process after the convolutions is easier and faster in DC.
- The fiber detection from SF data could possibly be done by Hough Transform (?).

Future Work

- Fiber tracking, and fiber recognition from convolution data.
- PIV/PTV using fluorescent tracer particles on the fiber water suspension.
- 3D Fiber PTV-PIV based on two cameras.
- Measuring velocity profiles and examining boundary layer behaviour on drag reduction regime (much higher fiber concentration).