Simultaneous Image Registration and Monocular Volumetric Reconstruction of a Fluid Flow

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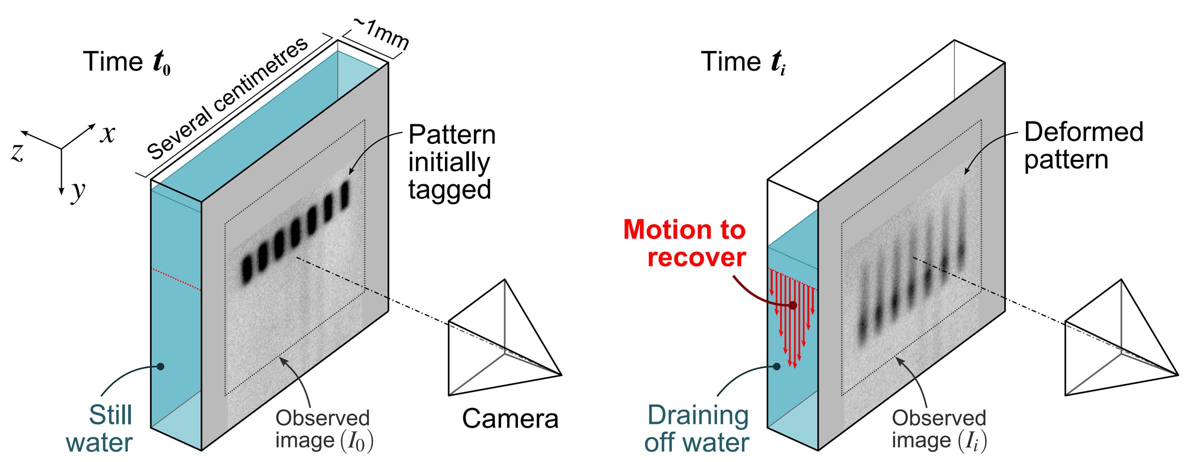
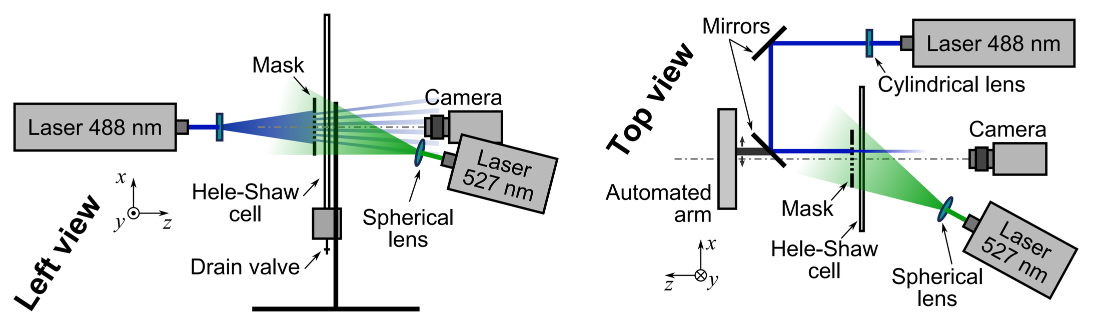
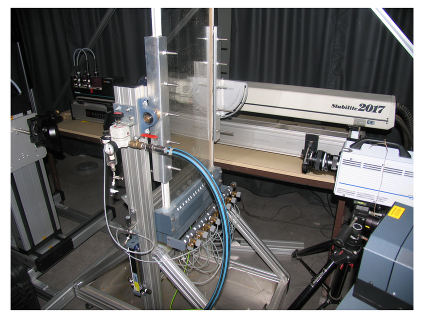
1. Context and Objective

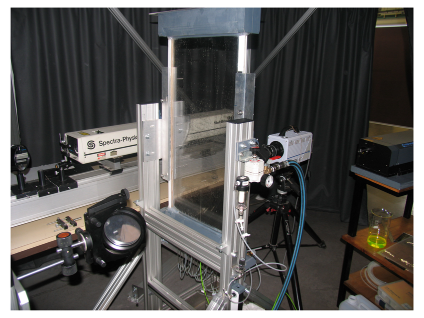


- **Computer vision** applied to experiments in **fluid mechanics**
- Densely measure the **Laminar Poiseuille Flow** in an **Hele-Shaw cell**
- Pattern printed in the liquid using **molecular tagging**
- Tracking and volume reconstruction by combining:
  - **direct image registration**
  - **a volumetric image formation model**
- Use as few physical assumptions as possible

2. Experimental Setup





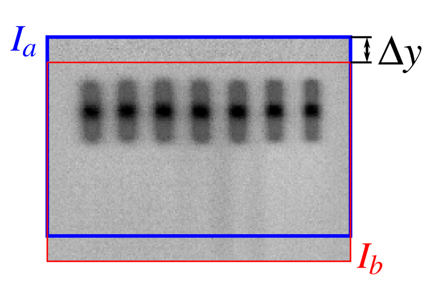


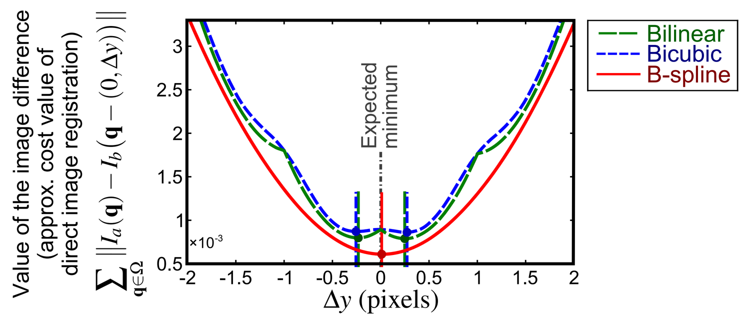
Molecular tagging based on photobleaching

- Truly non-invasive
- A molecular tracer (fluorescein) is uniformly mixed to the water
- When excited with a `green laser', the tracer becomes fluorescent
- The fluorescence can be inhibited using a powerfull `blue laser'

[Image Interpolation]

- **Bilinear** and **bicubic** interpolation introduce a **systematic bias**
- Problem solved by fitting a **regularized B-spline** to the image (the images are thus considered as continuous functions)

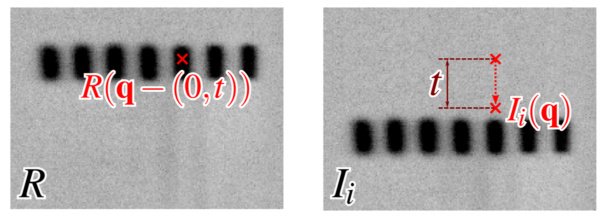




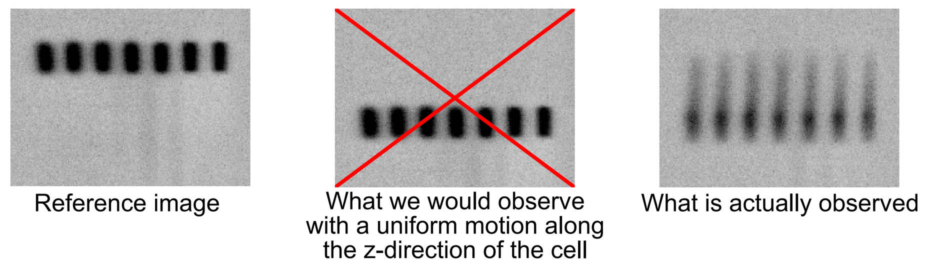
3. Direct Image Registration

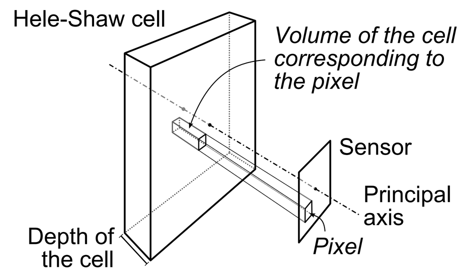
When the **brightness constancy assumption** is satisfied then direct image registration consists in minimizing the intensity difference between the input image (I_i) and the reference image (R):

$$\min_t \sum_{\mathbf{q}\in\Omega} \left(I_i(\mathbf{q}) - R(\mathbf{q}-(0,t))\right)^2$$



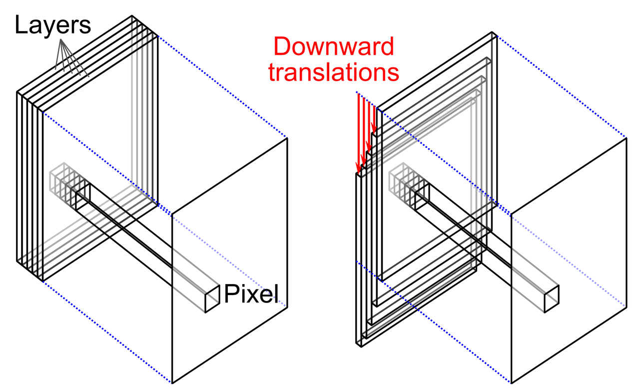
In our case, the brightness constancy assumption is **not** satisfied due to the image formation model and the nature of the observed flow:





4. Simultaneous Registration and Volumetric Reconstruction

Motion model and image formation model



Key idea: consider that the volume is made of layers moving independently from each other.

$$L_j(\mathbf{q}) = \frac{1}{n} R(\mathbf{q})$$

$$I_i(\mathbf{q}) \approx \sum_{j=1}^{n} L_j(\mathbf{q} - (0, t_{i,j}))$$

Additional hypotheses

Symmetry. The flow is symmetric with respect to the centre of the cell in the z-direction.
Positivity. All the translations are downward translations.
Temporal consistency. A layer never goes upward.
Spatial consistency. The inner layers are faster than the layers close to the walls of the cell.

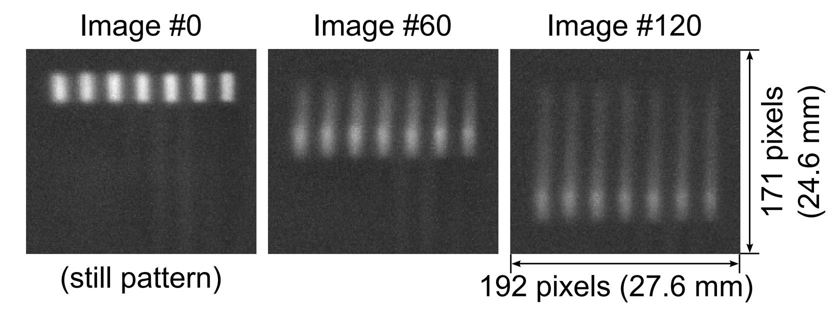
Final optimization problem

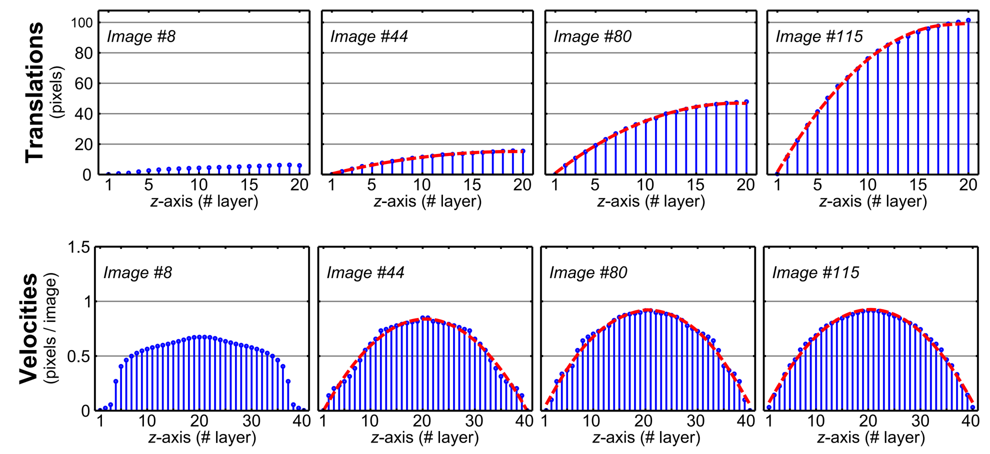
$$\min_{\mathrm{T}} \sum_{i=1}^{m} \sum_{\mathbf{q}\in\Omega} \left(I_i(\mathbf{q}) - \sum_{j=1}^{n} L_j(\mathbf{q} - (0, t_{i,j})) \right)^2$$

$$\text{subject to} \quad \begin{cases} t_{i,j} \geq 0 & \forall i = 1,\ldots,m, \forall j = 1,\ldots,n \\ t_{i+1,j} \geq t_{i,j} & \forall i = 1,\ldots,m-1, \forall j = 1,\ldots,n \\ t_{i,j+1} \geq t_{i,j} & \forall i = 1,\ldots,m, \forall j = 1,\ldots,n-1 \end{cases}$$

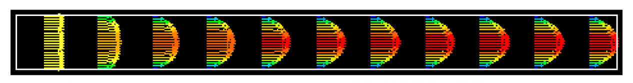
5. Results

Video sequence #1



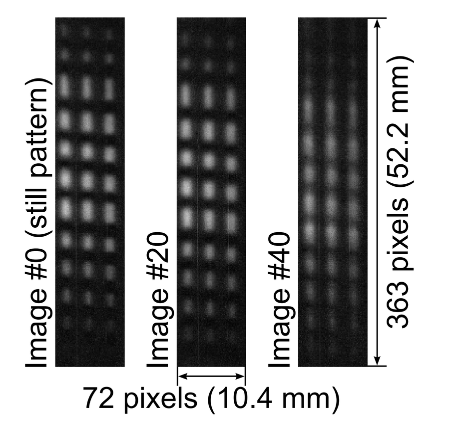


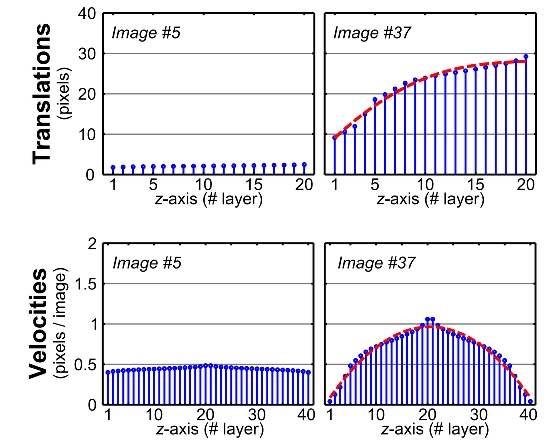
Theoretical Poiseuille flow model

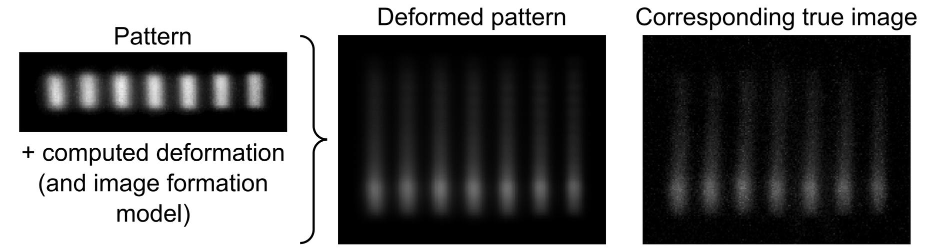


[http://www.columbia.edu/cu/gsapp/BT/RESEARCH/Arch-atmos]

Video sequence #2

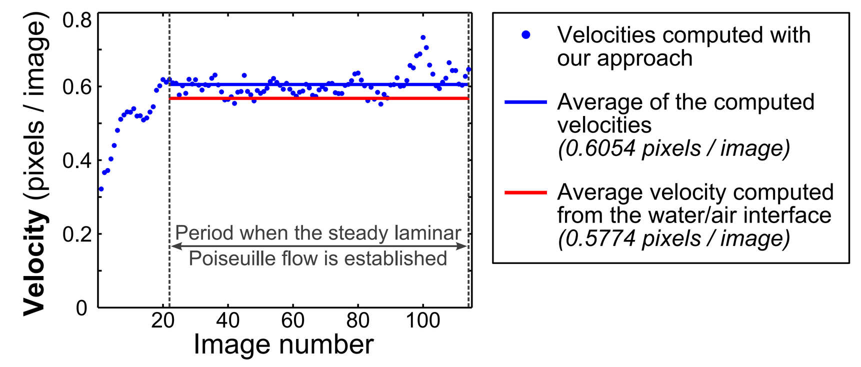




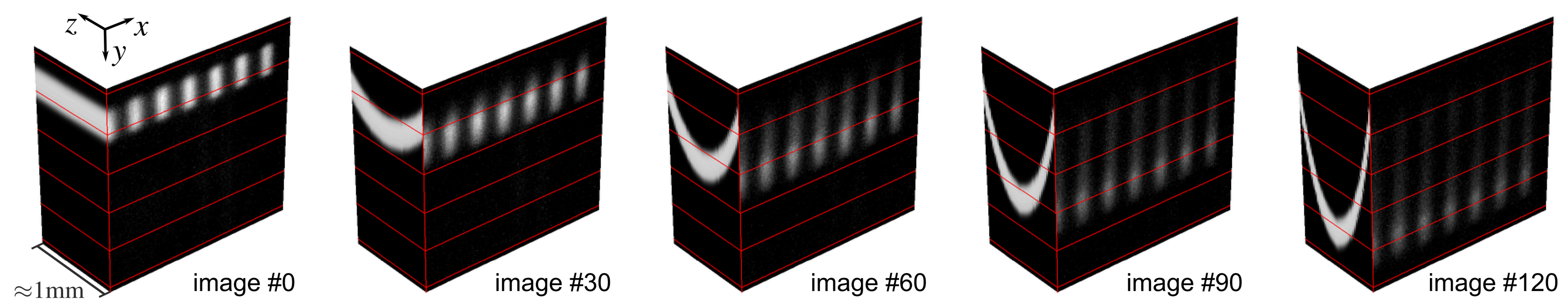


Comparison of the initial pattern warped using the translations computed with our approach and of the corresponding image of the video

Comparison between the computed velocities and the ground truth velocities (determined from the water/air interface)



3D view of the computed flow (front: acquired images, side: computed deformations)



Bibliography

C. Garbe *et al.* An optical flow MTV based technique for measuring microfluidic flow in the presence of diffusion and Taylor dispersion. *Experiments in Fluids*, 44:439–450, 2008.

S. Hosokawa and A. Tomiyama. Molecular tagging velocimetry based on photobleaching reaction and its application to flows around single fluid particles. *Multiphase Science and Technology*, 16:335–353, 2004.

I. Ihrke *et al.* State of the art in transparent and specular object reconstruction. *STAR Proceedings of Eurographics*, pages 87–108, 2008.

R. Szeliski. Image alignment and stitching: A tutorial. *Foundations and Trends in Computer Graphics and Vision*, 2:1–104, 2006.