Additive Manufacturing: Denoising and Particle Tracking

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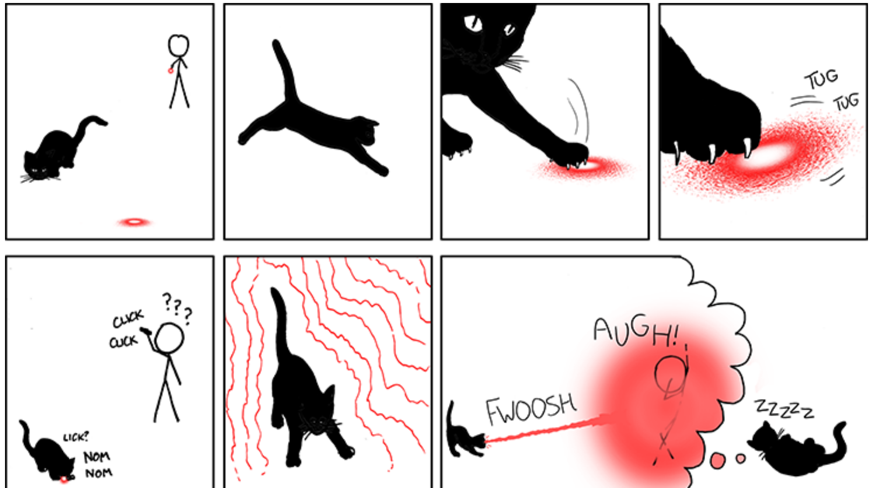
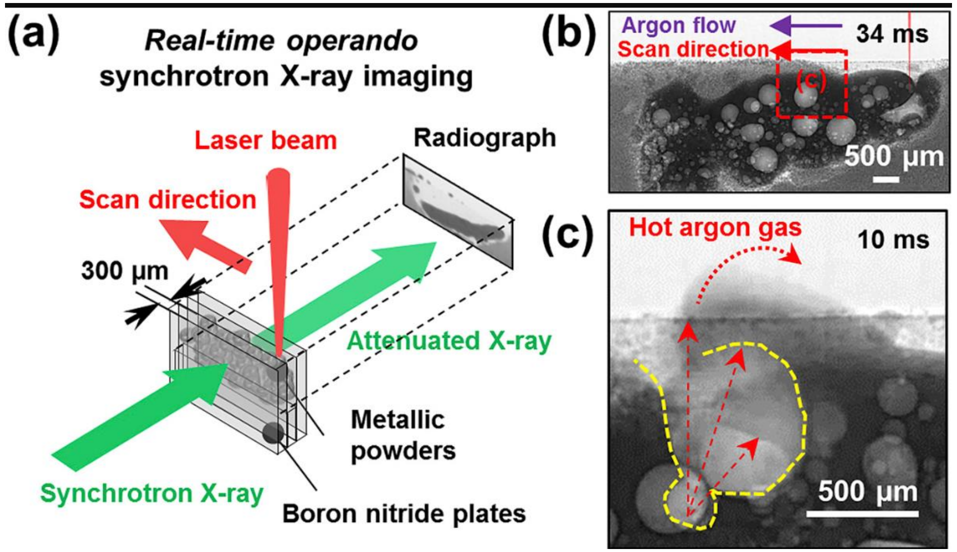
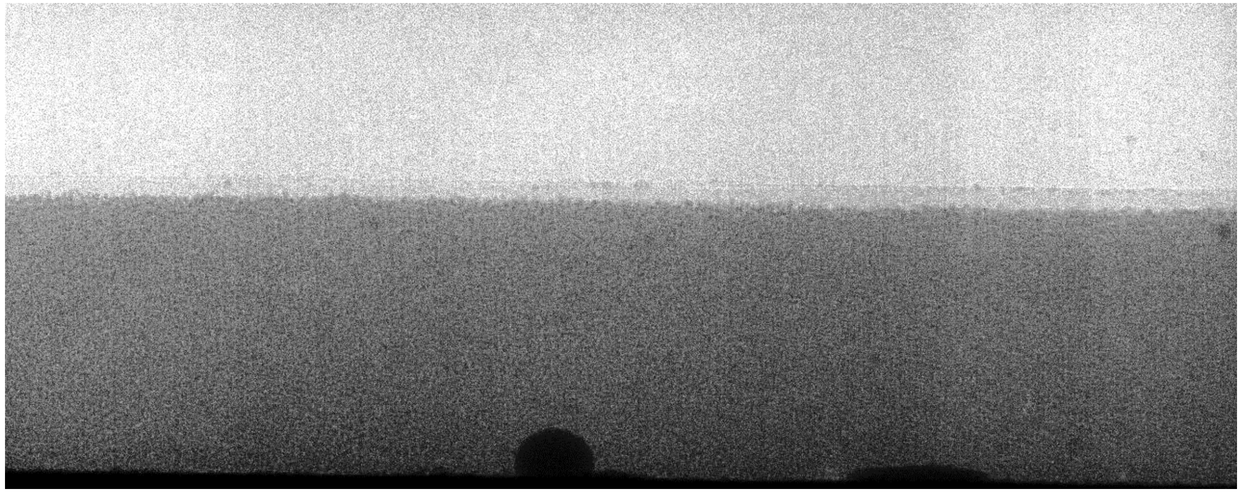


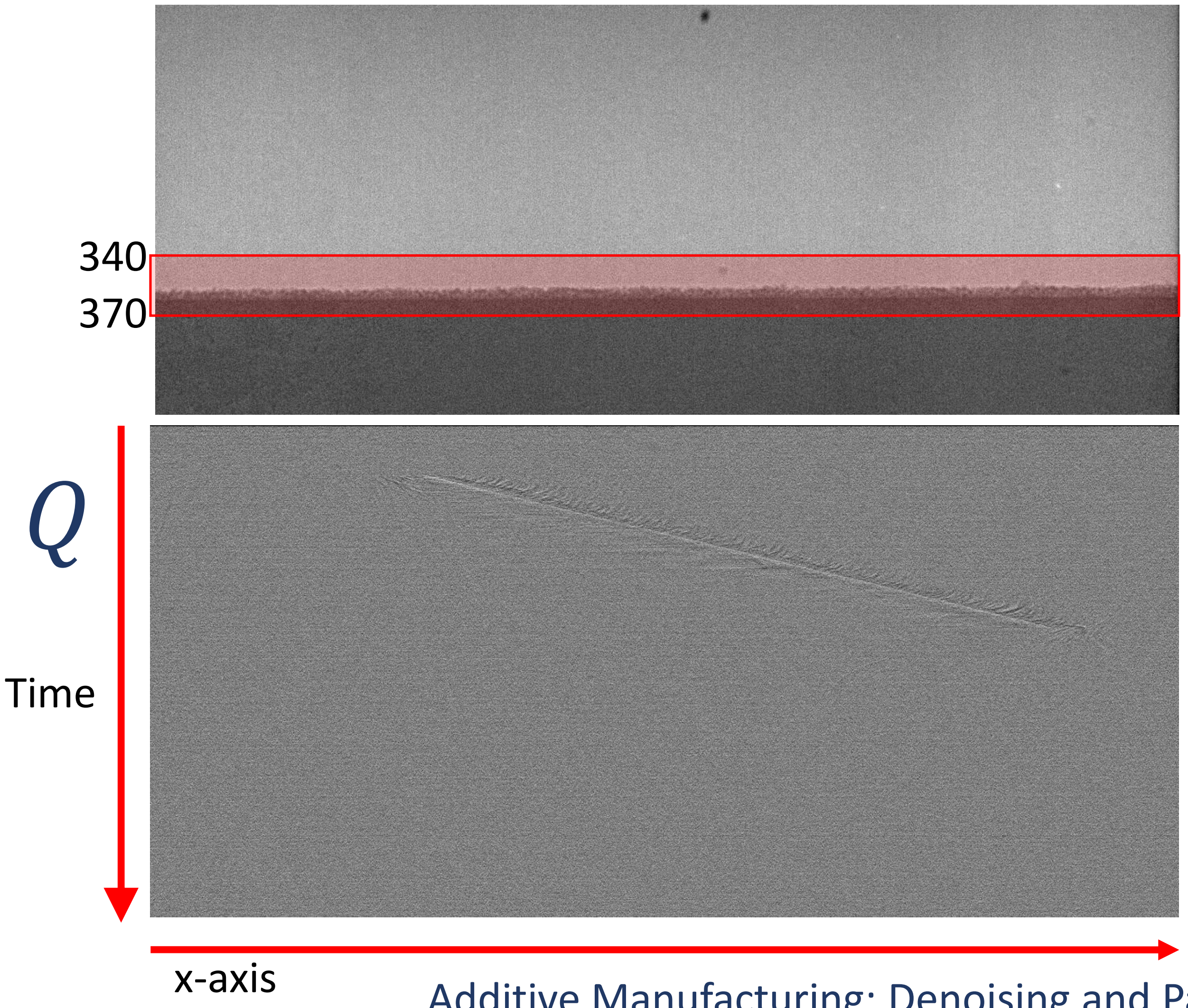
The Distilled Problem

- Find the velocity of the particles displaced from the surface
- Investigate the geometry of the molten material
- Tracking the laser across this image
- Obtain 3D information from the 2D images





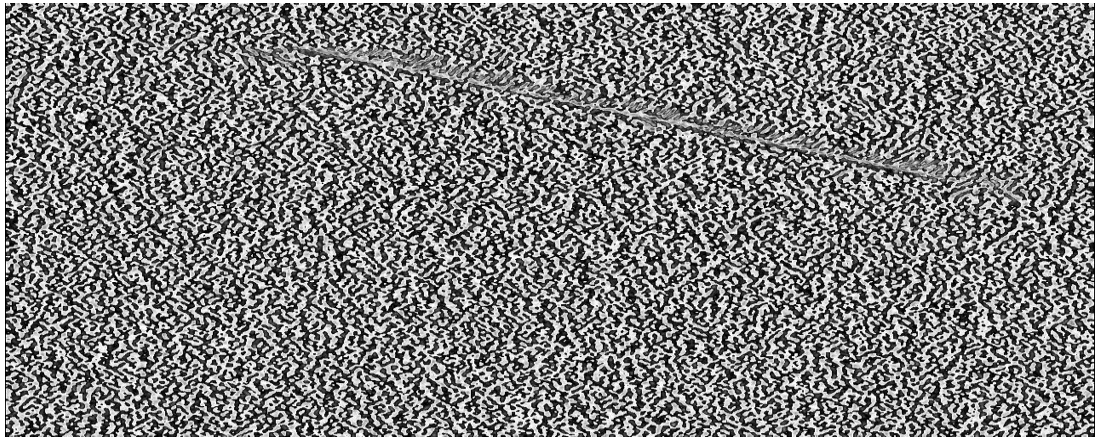
Current Work: Laser Tracking

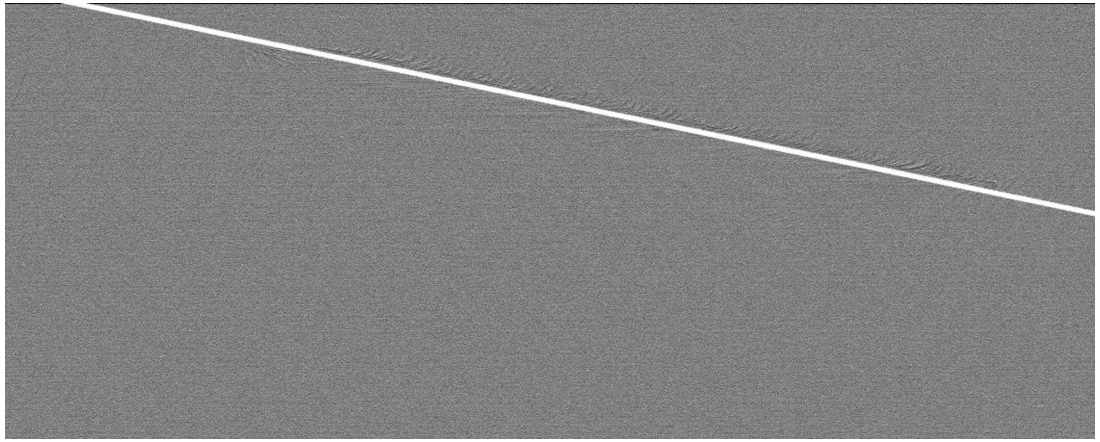


$$\frac{1}{30}\sum_{i=340}^{370}\left|u_{i,j}^{t}-u_{i,j}^{t+\delta t}\right| = Q_{t,j}$$

- Small strip across the boundary of new and old material considered
- Residuals taken between frames
- Vertical averages on residuals created a 1D vector for each frame
- New image of these concatenated vectors

Laser Tracking: Line Detection





Line Detection:

- Gradient – Sobel x-direction

$$G = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix} * Q$$

- Otsu thresholding
- Hough line detection

$$x\cos(\theta) + y\sin(\theta) - \rho = 0$$

  - Points (x, y) correspond to sinusoidal curves parameterised by (ρ, θ).
  - Intersection points in the parameter space correspond to points lying on the same straight line in the image space.
- Still more work to be done

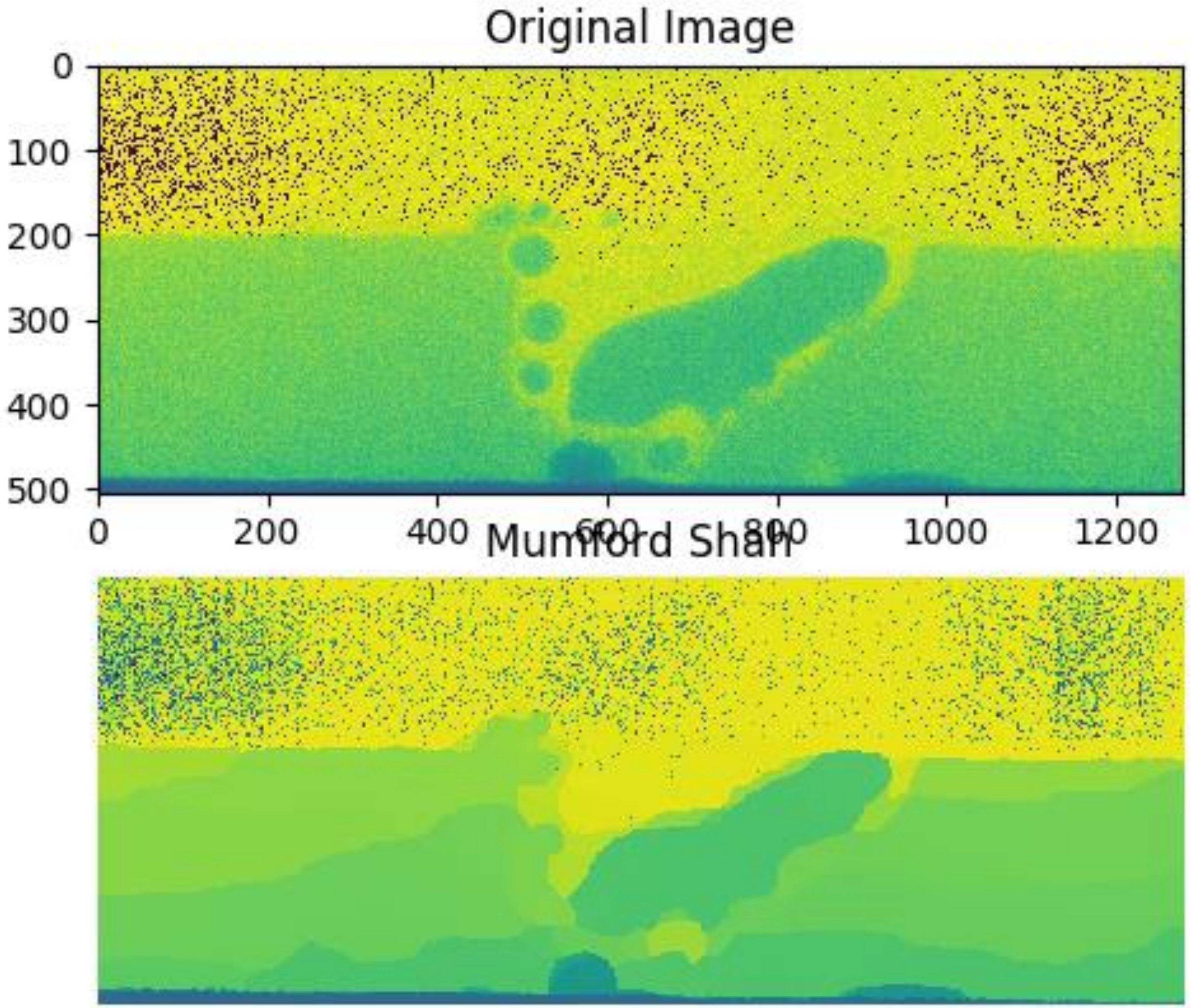
Current Work: Mumford-Shah smoothing and image segmentation

- AIM - segmentation of the molten area in order to investigate its geometry
- IDEA – Mumford-Shah implementation for denoising and segmentation
  - Find a noisy image u_0 wish to find a smoothed image u and a segmentation K which minimises the functional:

$$\int (u - u_0)^2 dx + \lambda \int |\nabla u|^2 dx + \alpha \cdot \text{ length}(K)$$

    - Fidelity term – ensures smoothed solution close to the noisy image
    - TV denoising term – smooths while maintaining discontinuities
    - Geometric term – minimises length of the edges of the segmentation

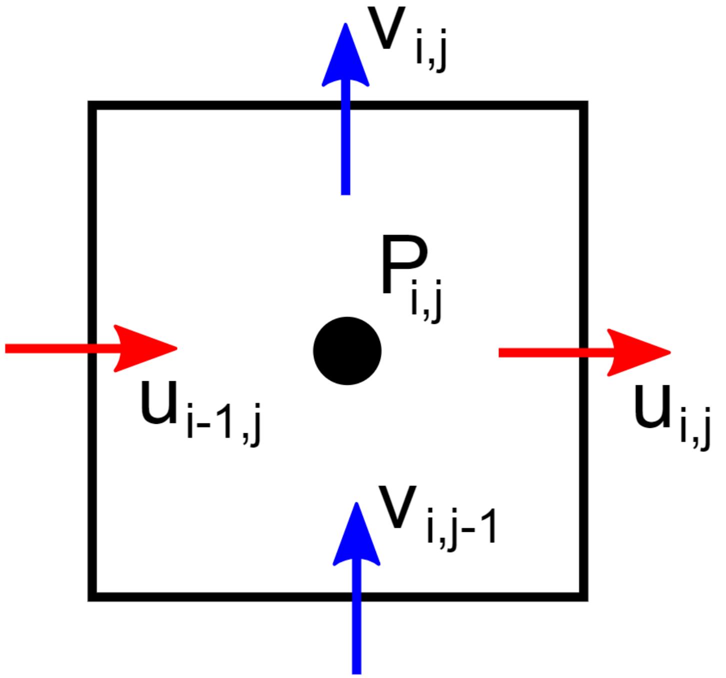
Mumford-Shah: Results



Current Work: Velocity Field Distribution

- Try to approximate the underlying velocity vector field from the video frames.
- Consider each video frame as a density field.

$$\rho_{i,j}^{t+\delta t} - \rho_{i,j}^{t} = u_{i-1,j} - u_{i,j} + v_{i,j-1} - v_{i,j}$$



- Least squares solver ($2n$ unknowns for n equations)

Advantages	Challenges
Avoids tracking individual particles	The source data is noisy
Should allow characterisation of the velocity field	Signal to noise ratio is poor

Velocity Field Distribution: Approach

- Let $v = v_\rho + v_\epsilon$

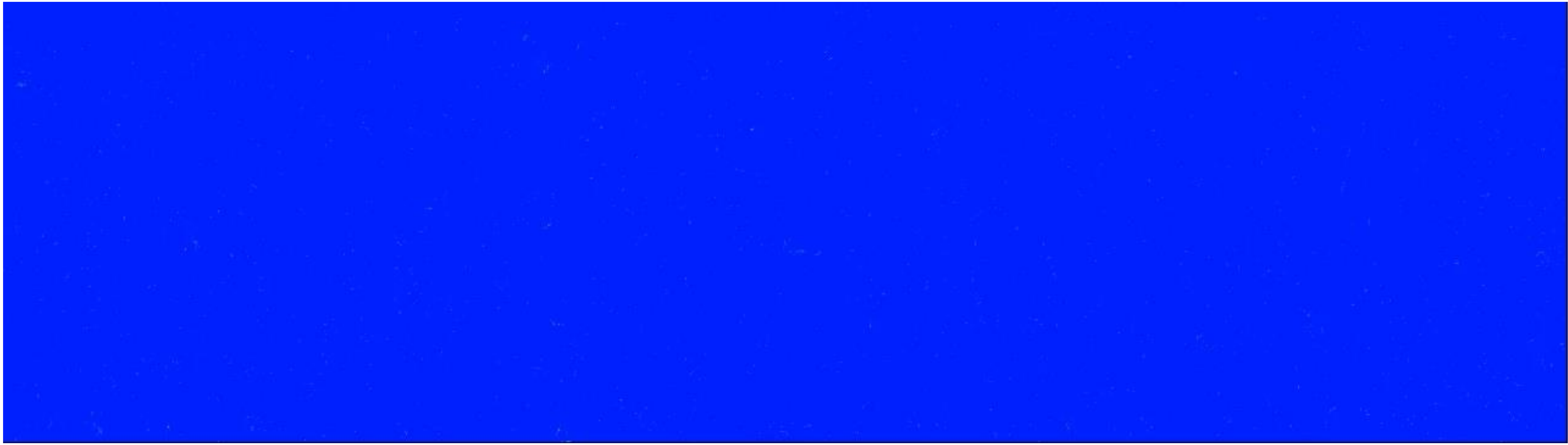
$$\int_0^\tau v_\epsilon d\tau = 0 = \int_{frame} v_\epsilon \, dx$$

- Idea: a "short" time average should remove errors in the velocity field
- Can also apply other noise reduction techniques prior to applying our approach.

Velocity Field Distribution: Results

Original

First Attempt



With denoising

Overlay

Future Work

- Kalman filters for image denoising
- Digital Image Correlation for particle tracking
- Develop a physical model
  - Detection of 3D motion from 2D images
- Echo state networks for analysing dynamics of the system

Questions!