Lawrence Livermore National Laboratory

Feature Extraction and Tracking in Fusion Plasma

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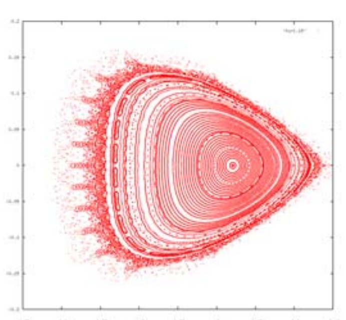
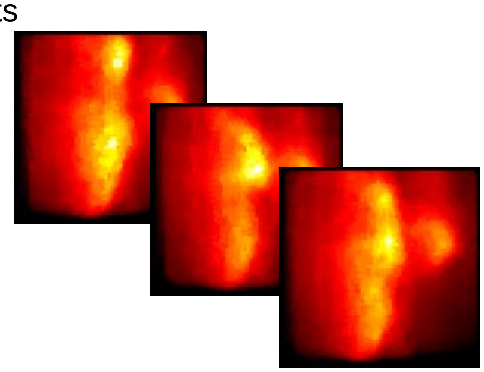
Feature Extraction and Tracking: current projects in the SDM center

- Classification and characterization of Poincaré plots
  - Data from both simulations and experiments
- Characterization and tracking of blobs in plasma
  - Data from experiments



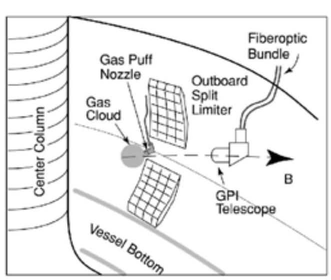


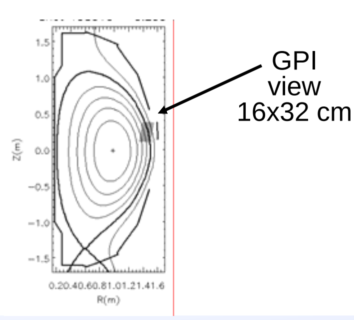
We want to understand the turbulence which causes leakage of the plasma

- Requirements for fusion – high temperature and confined plasma
- Fine-scale turbulence at the edge causes leakage of plasma from the center to the edge
  - Loss of confinement
  - Heat loss of plasma
  - Erosion or vaporization of the containment wall

The Gas-Puff Imaging diagnostic is used to view the coherent structures in edge turbulence

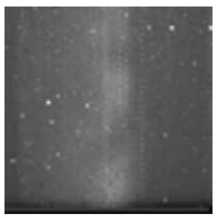
- Turbulence in the form of density filaments highly elongated in the direction of the magnetic field
- Inject a gas cloud in the torus, and capture the intersection of the cloud with the filament using a camera which views the filament along the magnetic field

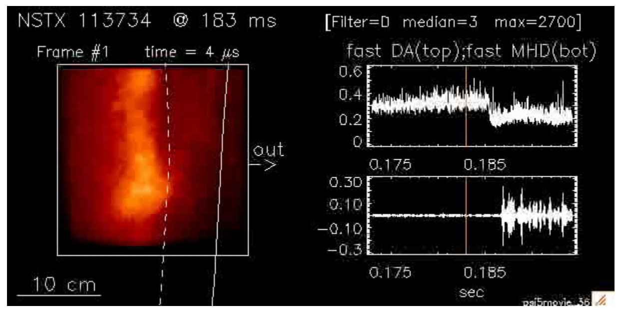




Analysis of edge turbulence using images from NSTX (joint work with Nicole S. Love)

- PSI-5 camera capture GPI images
  - 300 frame sequences taken at 250,000 frames/sec
  - 16-bit images with 64x64 pixels



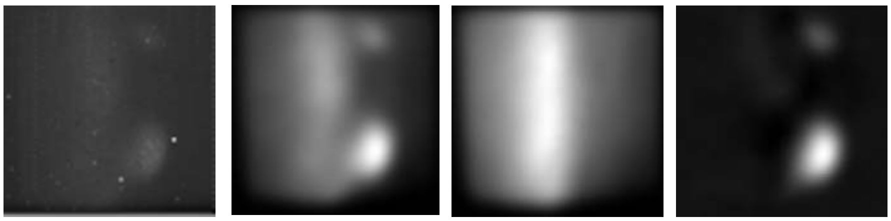


Goals of our analysis and the challenges

- Goals: Identify, extract, characterize, and track coherent structures (blobs) to compare experimental data with theory
- Challenges to the analysis
  - coherent structures are poorly understood empirically and not understood theoretically
  - no known ground-truth
  - noisy images
  - variation within a sequence

Preprocessing of images (sample image from sequence 113734 frame 31)

- 3x3 median filter (de-noising)
- 11x11 Gaussian filter (std dev= 0.4) (de-noising)
- Background subtraction (300 frame median)



raw image | **after de-noising** | **background** | **after dividing out background**

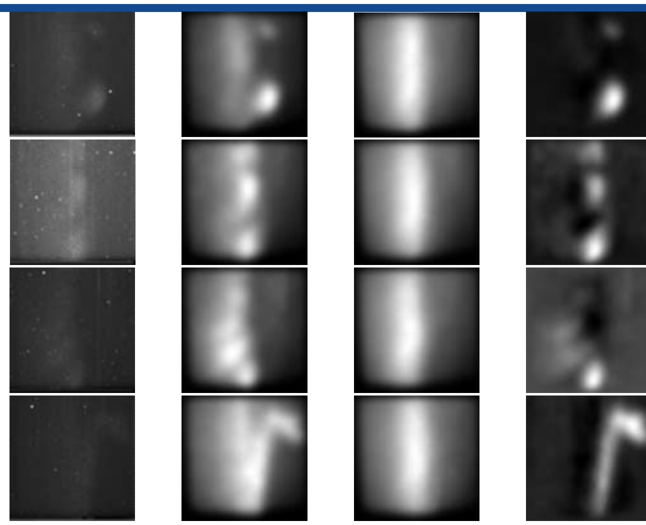
We selected 4 sample sequences, each 300 frames/sequence

113734 frame 31

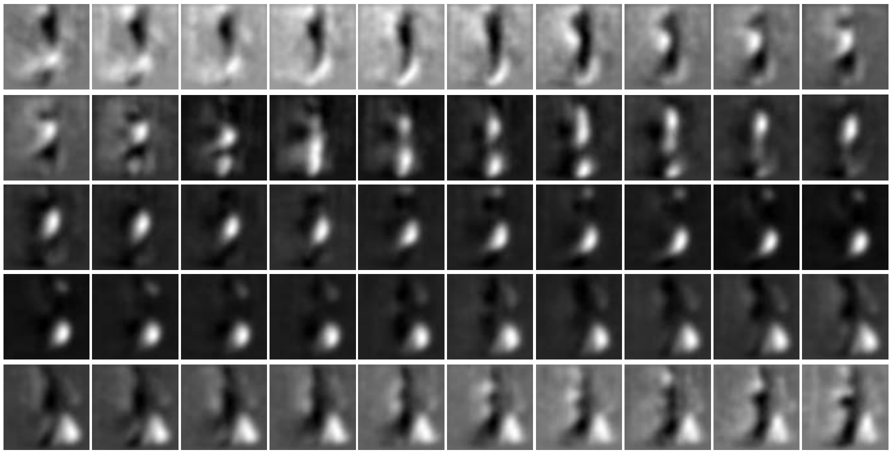
113735 frame 10

113737 frame 13

113739 frame 60



Example frames to segment (sequence 113734: frames 1-50)

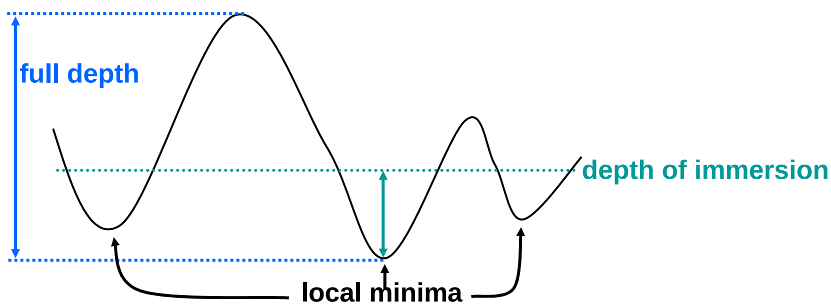


We investigated several segmentation methods

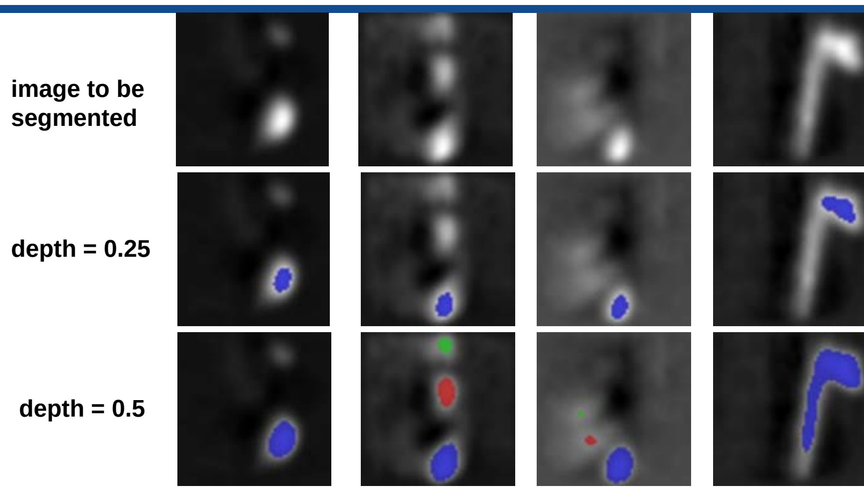
- Immersion-Based
  - Basic immersion
  - Constrained watershed
  - Watershed merging
- Region Growing
  - Seeded region growing
  - Seed competition
- Model-Based
  - 2-D Gaussian fit

Basic immersion technique

- Inverse image as a topographic relief
- Elevations are intensities
- Make holes at minima
- Immerse image to certain depth



Results from the basic immersion technique

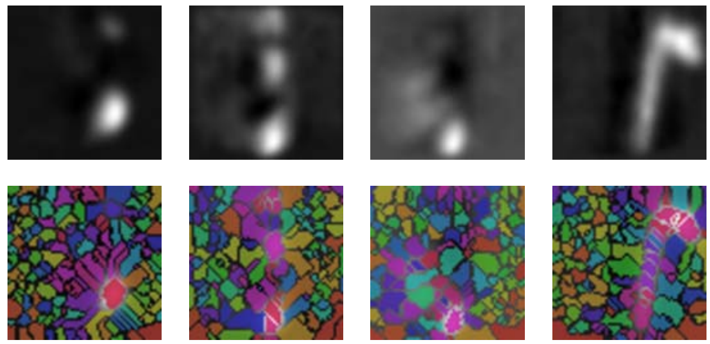


Regions displayed are below the depth of immersion

Watershed algorithm

image to be segmented

results after watershed



- Possible solutions to over-segmentation
  - constrained watershed (before watershed)
  - watershed merging (after watershed)

Constrained watershed*

1. Clean image ***(optional)*** – morphological operations
2. Identify foreground markers – local regional maxima
3. Identify background markers – threshold image where inter-class variance of image histogram is maximized**
4. Set foreground and background markers to be minima of the gradient image
5. Apply watershed to gradient image with new minima

* www.mathworks.com
** Otsu, SMC-9, ’79

Watershed merging*

1. Apply watershed to the gradient image
2. Merge all regions entirely contained in the background markers
3. The background region and remaining regions are merged in order of similarity until a threshold is reached
4. Region adjacency and means are updated after each merge (threshold is set once, not updated)

$$\delta(R_i, R_j) = a(i,j)(\mu(R_i) - \mu(R_j))^2$$

$$a(i,j) = \begin{cases} 1, & \text{if } R_i \text{ is adjacent to } R_j \\ 0, & \text{otherwise} \end{cases}$$

$$\mu(R_i) = \text{mean of } R_i$$

$$\text{threshold} = w \max(\delta(R_i, R_j)), \quad w = 0.02$$

* Haris, ICIP,'98

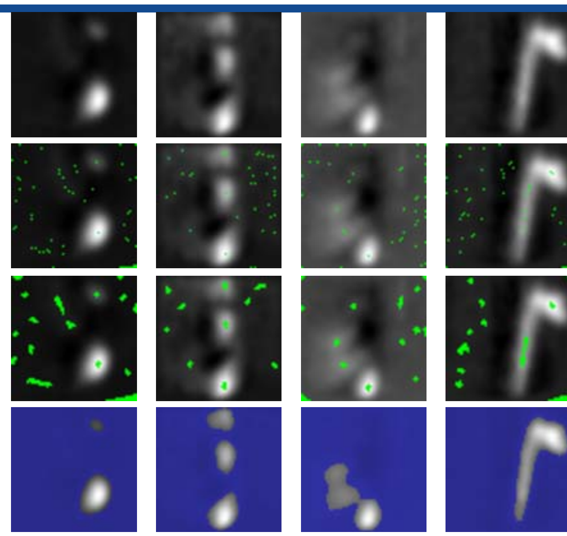
Foreground and background markers

image to be segmented

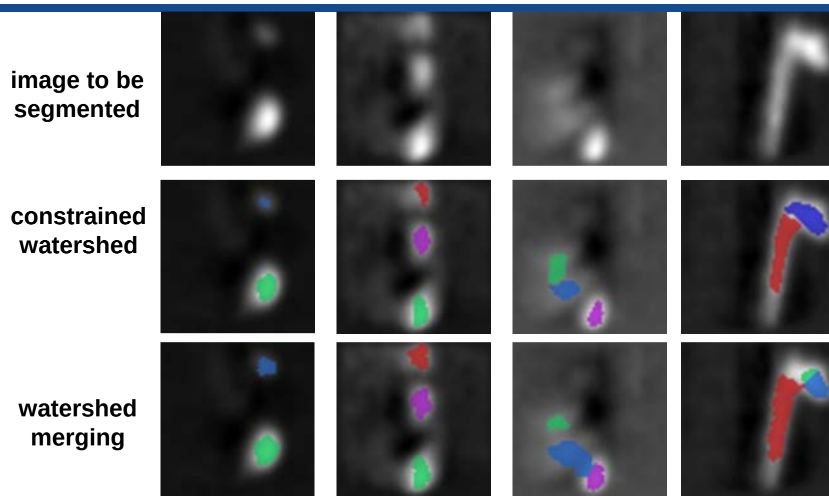
foreground markers (before cleanup)

foreground markers (after cleanup)

background markers



Constrained watershed and watershed merging reduce over-segmentation



Regions displayed have at least one foreground marker not in the background

Seeded region growing method

- Seeds are foreground marker pixels
- Each seed pixel is a region
- A region is grown if a neighbor of a pixel in the region is not labeled and is within a threshold of the seed pixel's intensity

$$\text{threshold} = w(s_k - I_m)$$

$$s_k = \text{intensity at the location of seed } k$$

$$I_m = \text{intensity minimum of the image}$$

$$w \in [0,1], \quad w = 0.08$$

Seed competition technique*

- Seeds are foreground marker pixels (before cleanup) and background marker pixels
- We compare a pixel to neighboring pixels that are already assigned. If the pixel is more similar to one of the neighbors, the pixel is assigned to the seed of that neighbor.

$$\delta(p_s, q) = 1 - \exp\left(\frac{-1}{2\sigma^2} \left(\frac{I(p_s) + I(q)}{2} - I(s) \right)^2 \right)$$

$$p_s = \text{pixel labeled with seed } s$$
$$q = \text{neighbor of } p_s$$
$$\sigma = \text{standard deviation of the image}$$
$$I(\cdot) = \text{intensity of pixel}$$

* Falcao, Proc XVII Brazilian Symp CGIP, '05

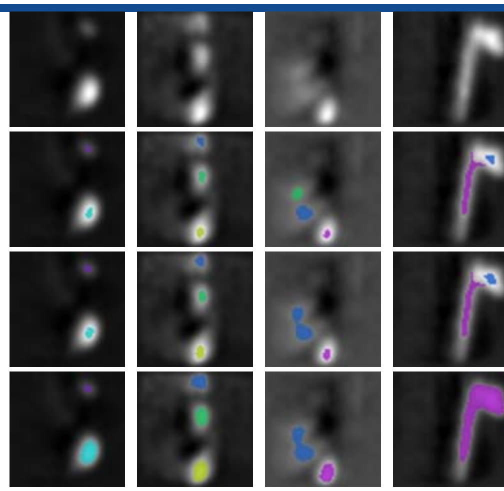
Results for seeded region growing and seed competition

image to be segmented

seeded region growing (before cleanup)

seeded region growing (after cleanup)

seed competition



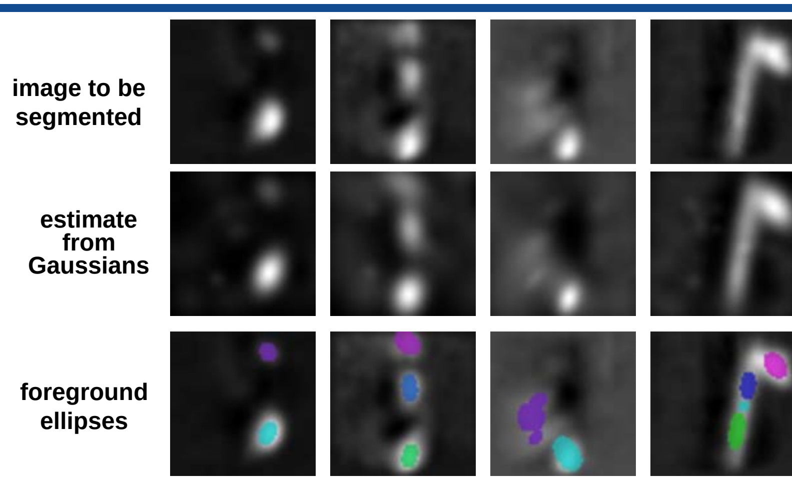
Regions displayed have at least one foreground marker not in the background

2-D elliptic Gaussian fit*

- Parameters: center, mean, major and minor widths, and the angle of major axis
- Initial guess: key foreground markers (before cleanup)
- Each iteration is a least square fit of the Gaussian functions to the data (10 iterations max.)
- The resulting Gaussian functions are matched to the key foreground markers; unmatched key foreground markers are added to the resulting Gaussian functions as the guess of the next iteration

* www.aoc.nrao.edu/aips/

2-D elliptic Gaussian fit



Ellipses displayed have a center position not in the background

Observations

- Seeded region growing can give rise to strangely-shaped regions

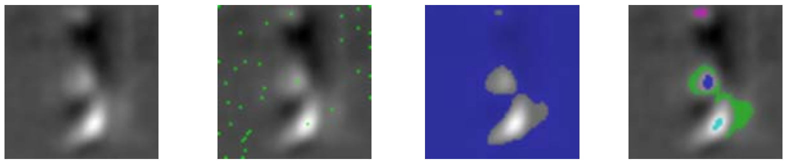


image to be segmented | foreground markers (before cleanup) | background markers | seeded region growing

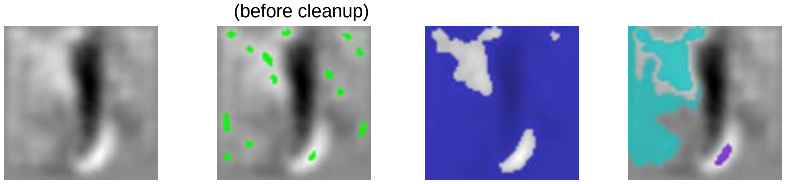


image to be segmented | foreground markers (after cleanup) | background markers | seeded region growing

Observations

- Methods based on foreground and background markers are sensitive to the existence and location of markers

image to be segmented | foreground markers (before cleanup) | background markers | constrained watershed | seed competition

- Foreground markers are regional maxima and do not capture faint tails

image to be segmented | foreground markers (before cleanup) | background markers | constrained watershed | seed competition

Observations

- Basic immersion – difficult to determine optimum depth to detect faint coherent structures

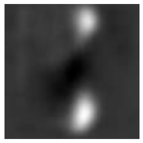
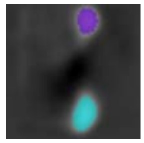


image to be segmented


immersion depth = 0.5

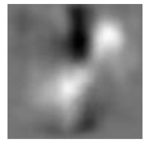
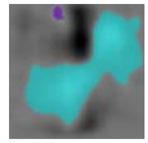


image to be segmented


immersion depth = 0.5

- Gaussian fit gives good estimates; difficult to find the coherent structures

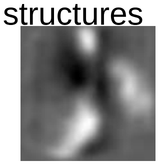
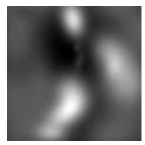
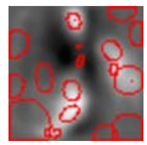


image to be segmented


estimate from Gaussians


ellipses from Gaussians

We need to refine the image processing techniques to make them more robust

- Basic immersion, watershed merging, and seeded region growing can be sensitive to threshold values
- Seed competition and constrained watershed are sensitive to markers
- Gaussian fit gives good estimates, challenge is to translate estimate into coherent structures
- A method is needed to map segmentation results to coherent structures

Next steps

- Coherent structures in plasma turbulence:
  - investigate further - 2-D Gaussian fit, constrained watershed, and seed competition
  - apply to other short sequences
  - investigate applicability to longer (7000 frame) sequences
- Classification of Poincaré plots
  - investigating the extraction of robust features representing the orbits

Acknowledgements

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http://www.llnl.gov/CASC/sapphire/