Rapid cm-scale 3D PIV/PTV with plenoptic macro photography

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Background

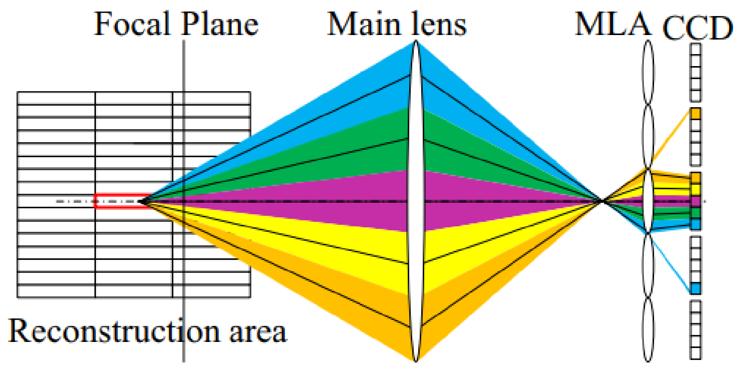
- Tomo-PIV/PTV systems require the use of multi-cameras. Large experimental space and multi-path optical access may not be feasible for small-scale measurement.

- Considering the sparse characteristic of particle distribution in small-scale measurement, the high computation power of algebraic algorithms (e.g., MART) for light field systems makes them not very efficient.

- Based on rapid 3D particle reconstruction with orthographic $system^*$, we improve this approach with modulated calibration and parallel computing for the perspective lens since particle motions are essential to study the local flow motions.

$$I(x_i, y_i) = \sum_{j \in N_i} W_{i,j} E(X_j, Y_j, Z_j)$$

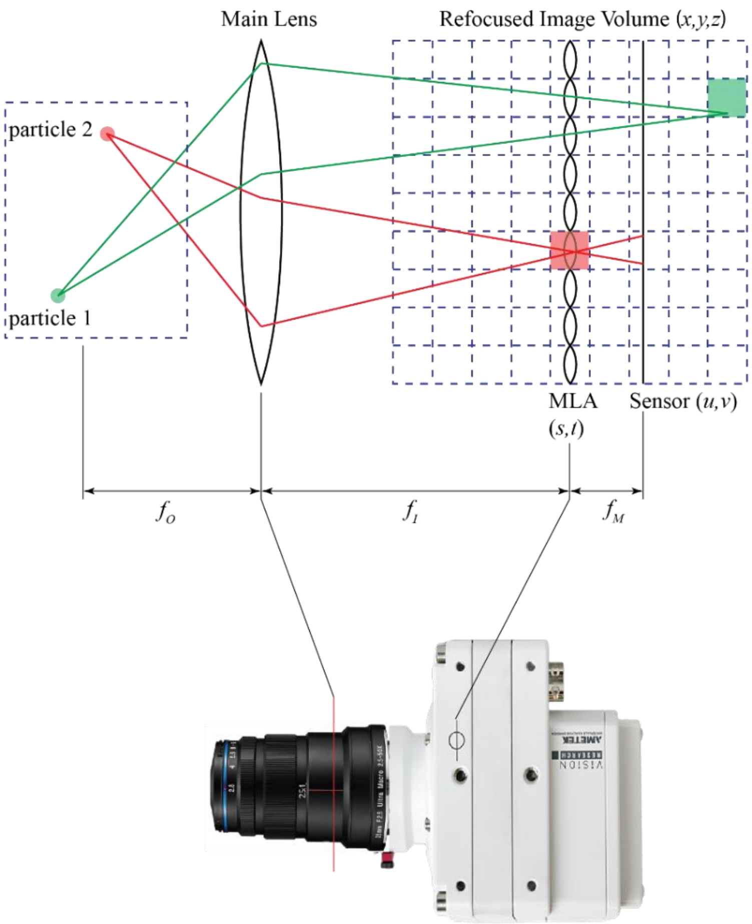
$$E_j^{k+1} = E_j^k + \mu \frac{\sum_i \left(\frac{I_i - \sum_{n=1}^{N} W_{in} E_n^k}{\sum_{n=1}^{N} W_{in}} \right) W_{i,j}}{\sum_i W_{i,j}}$$

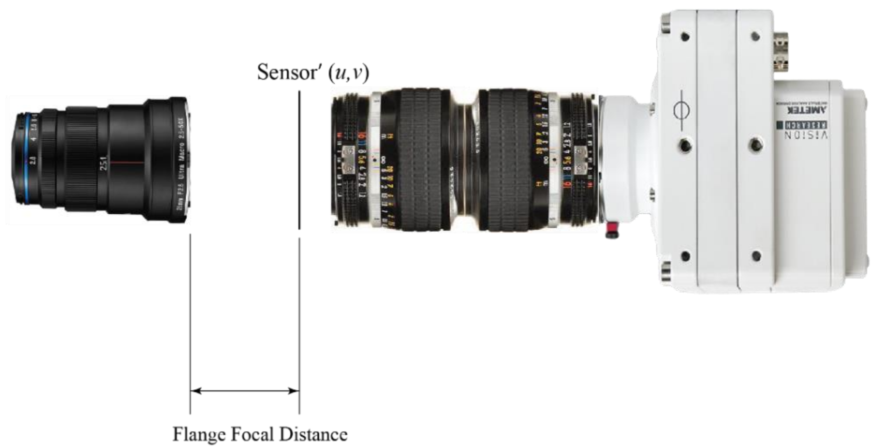


Shi, Shengxian, et al, *experiments in Fluids* 58, no. 7 (2017): 1-16.

* Hong and Chamorro *Lab on a Chip* 22.5 (2022): 964-971.

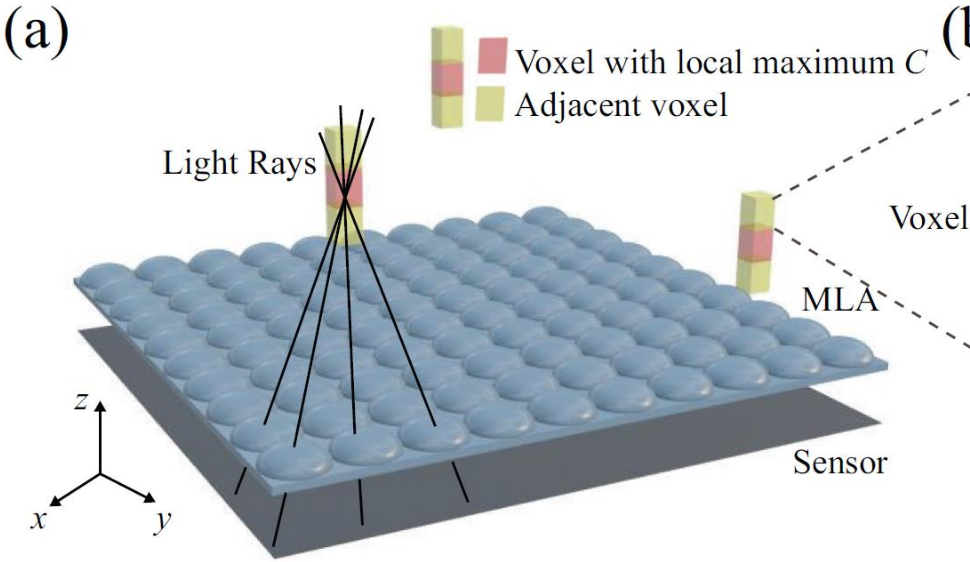
Light field camera



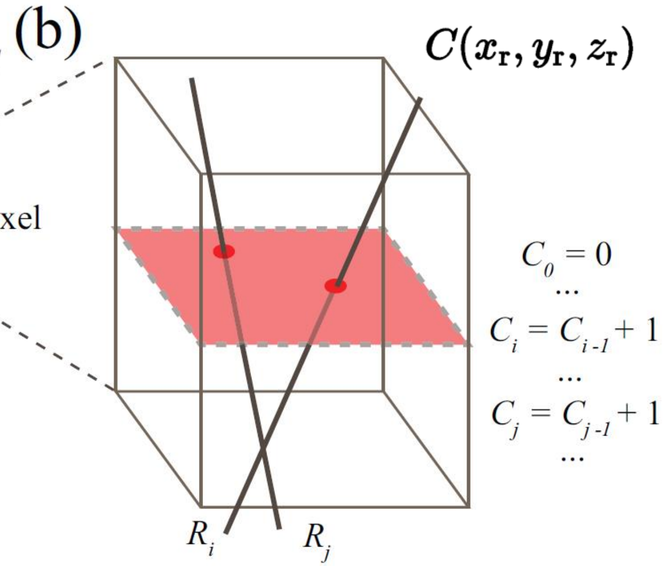


Light field system with 25mm f/2.8 2.5 X macro lens.

Reconstruction algorithm



3D light ray diagram around MLA.



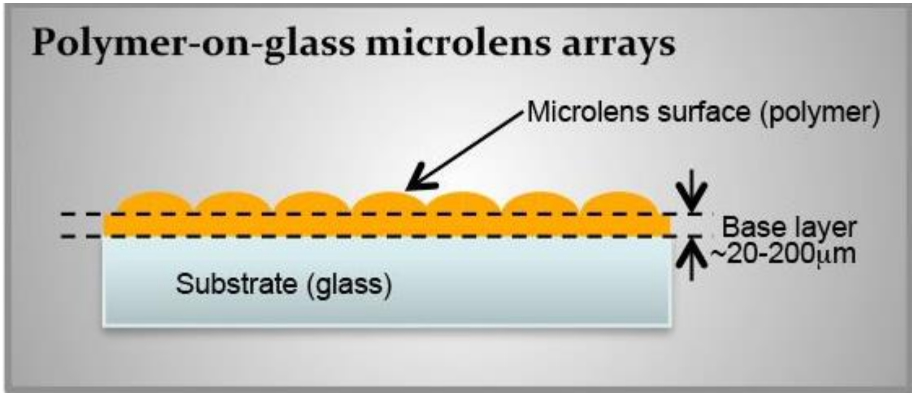
Increment of ray counter in one voxel.

Hong and Chamorro, *Lab on a Chip* 22.5 (2022): 964-971.

Experimental setup

(a)

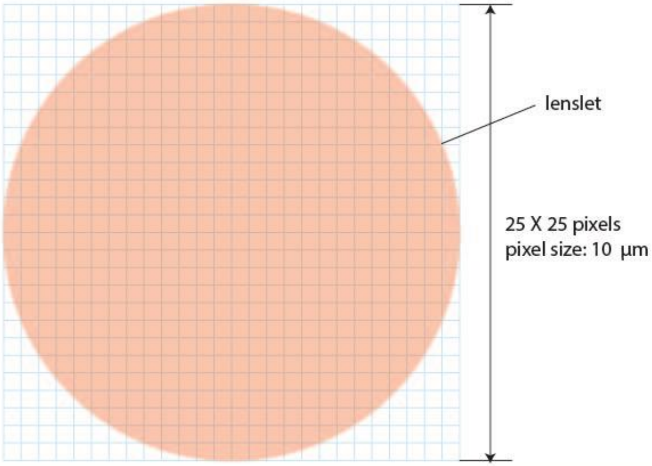
MLA-S250-f10



$$f_M = 2.5\ mm, P_l = 250\ \mu m$$

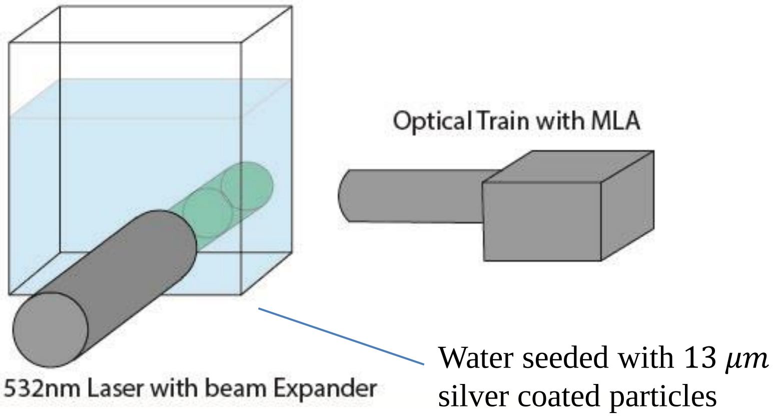
Side view of MLA.

(b)



Pixels underneath individual lenslet.

(c)



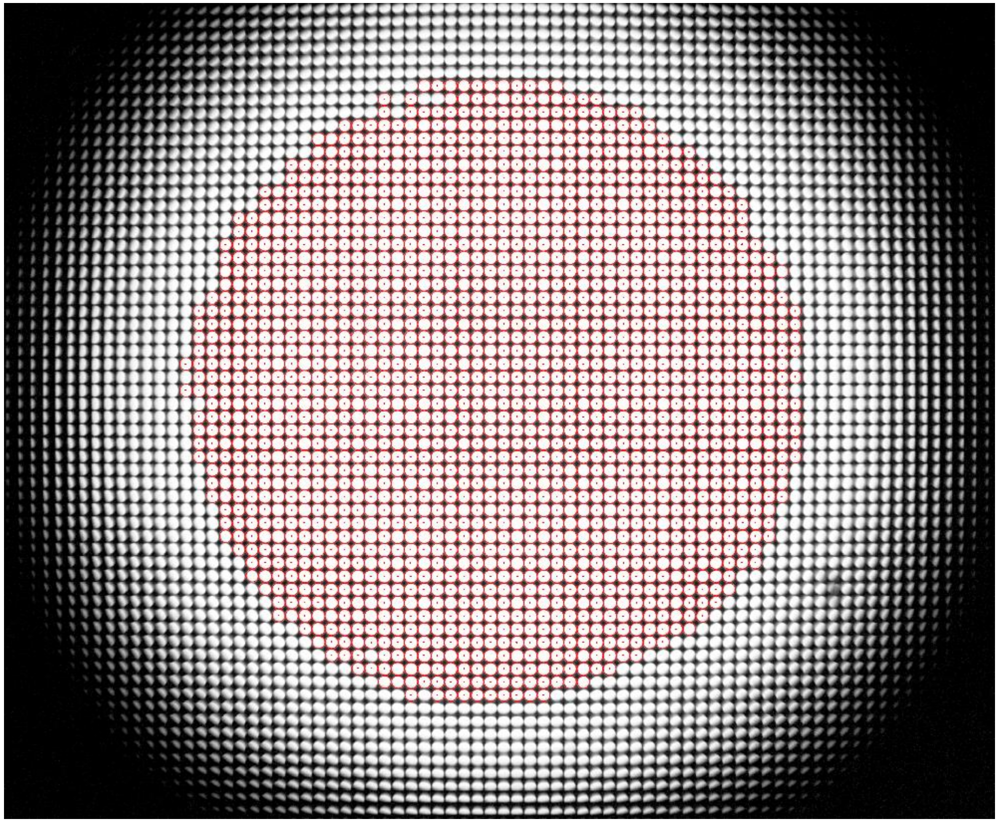
Basic schematic of experimental setup

$$\Delta x = \Delta y = \frac{P_l}{M} = 100\ \mu m$$

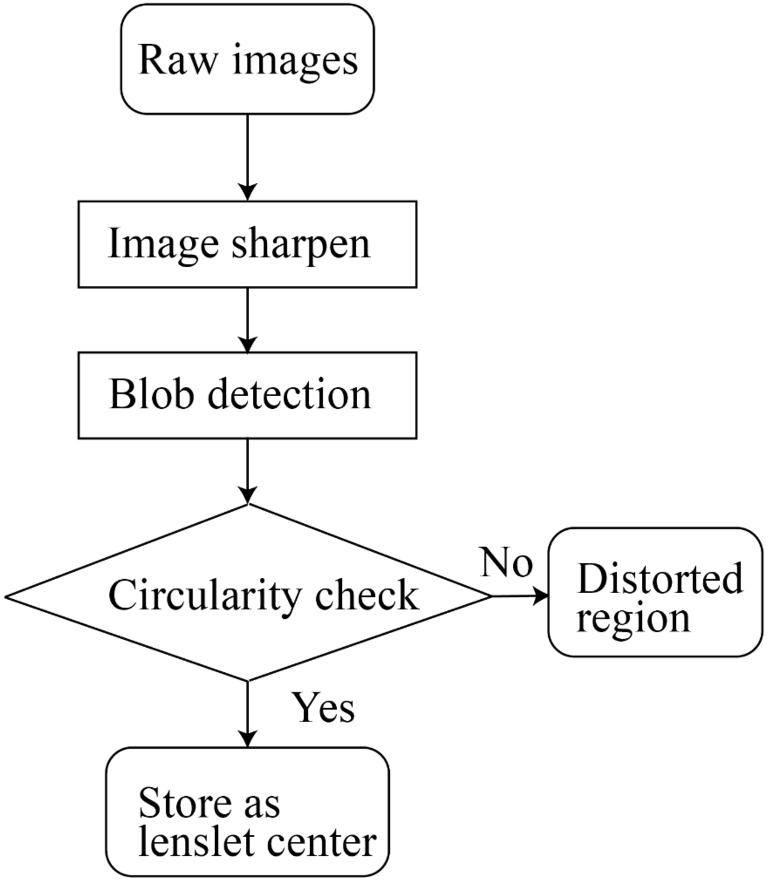
$$\Delta z = \frac{f_M}{M^2} = 133\ \mu m$$

Calibration

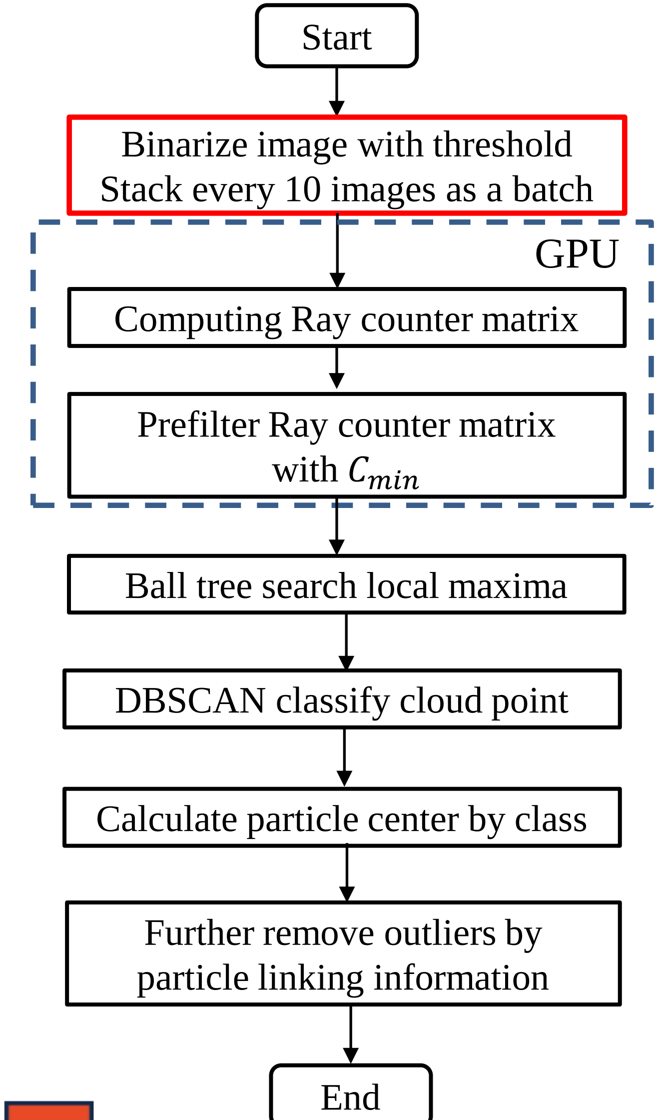
(a)



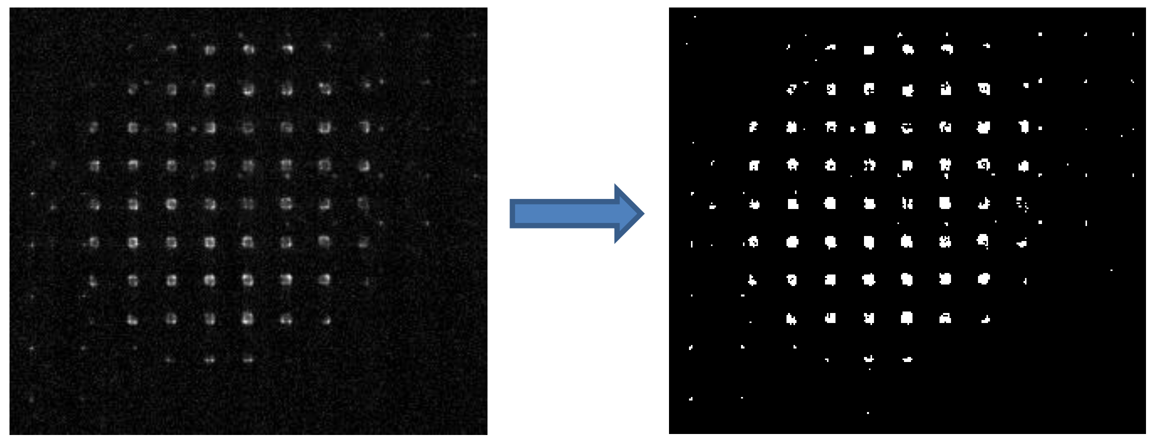
(b)



3D particle reconstruction



A binary image with a threshold is calculated from a raw image without particles to reduce the data transfer time.

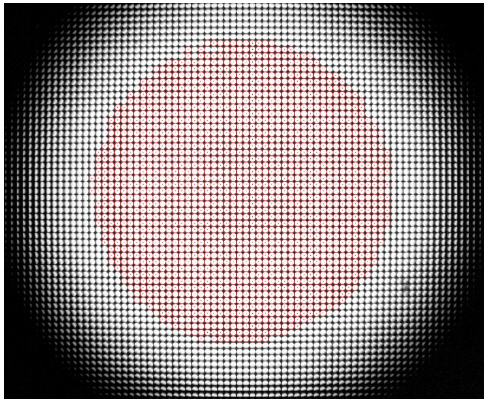


Stack images to enable concurrent processing with multiple streams.

3D particle reconstruction

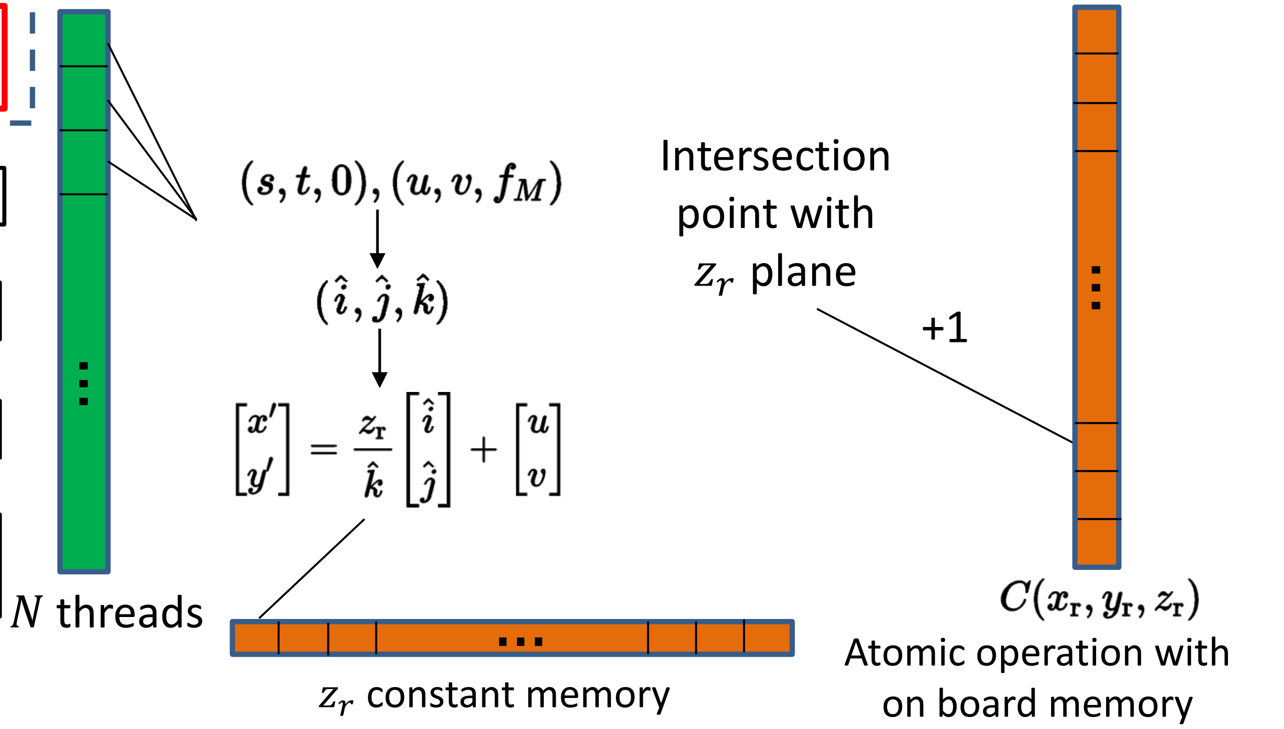
Start
↓
Binarize image with threshold
Stack every 10 images as a batch
↓
GPU:
- Computing Ray counter matrix
- ↓
- Prefilter Ray counter matrix with C_{min}

↓
Ball tree search local maxima
↓
DBSCAN classify cloud point
↓
Calculate particle center by class
↓
Further remove outliers by particle linking information
↓
End

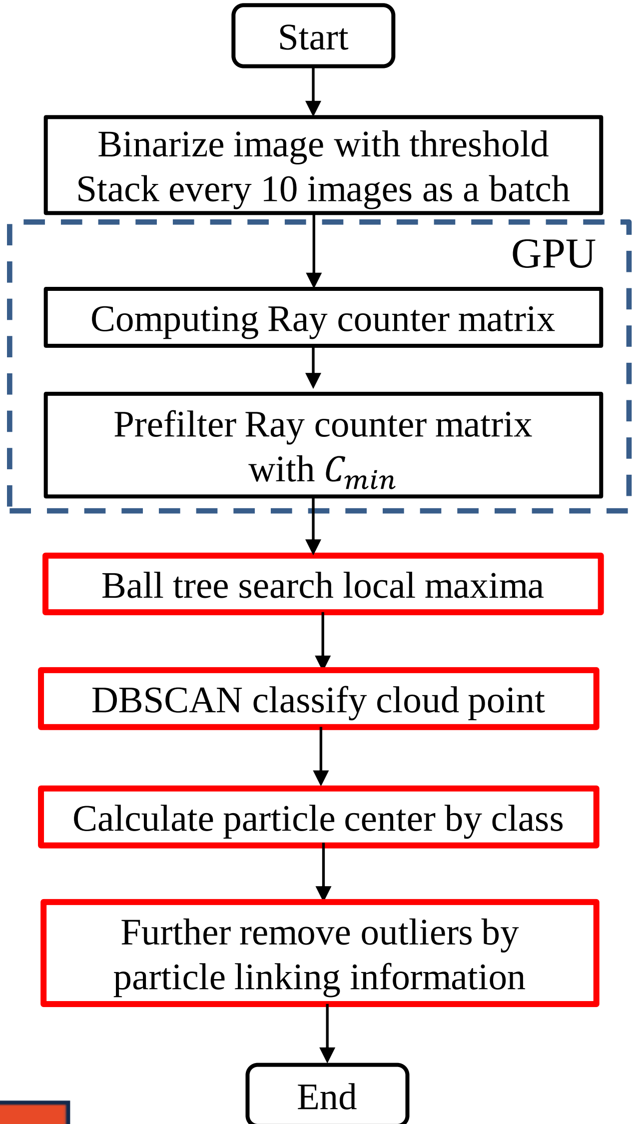


$$Q = \begin{bmatrix} | & | & | & | \\ u & v & s & t \\ | & | & | & | \end{bmatrix}, \quad Q \in C^{N\times 4}$$

N: number of valid pixels
(u, v): pixel coordinates on the sensor
(s, t): center coordinates of lenslet

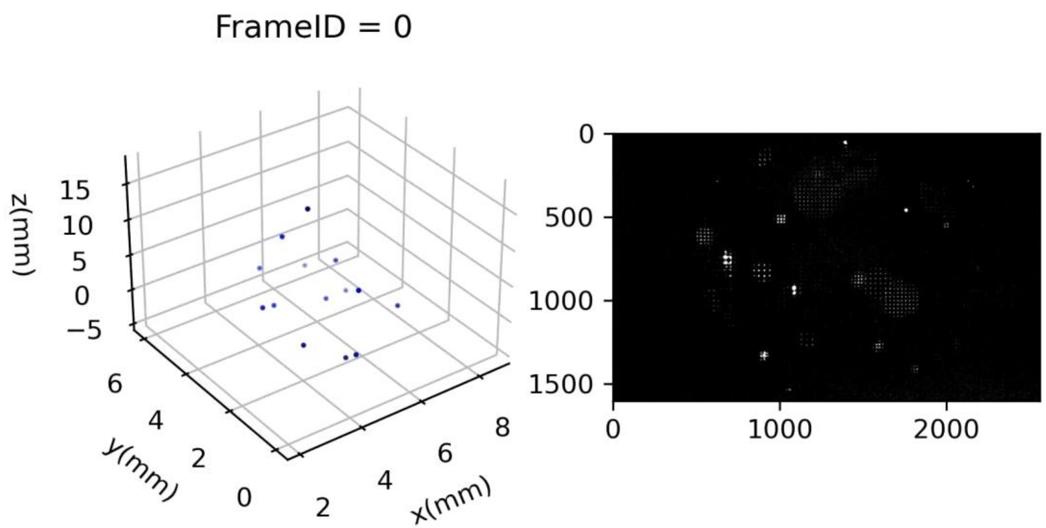


3D particle reconstruction



$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}, M = \frac{d_i}{d_0} = 2.5$$

$$1.4f + \delta_0 = \frac{3.5f^2 + \delta_i f}{2.5f + \delta_i}$$



Overall reconstructed time for each frame : 280 ms

Remarks and ongoing work

- We propose an improved non-iterative fast method for sparse particle reconstruction with a nonorthographic system.
- Reconstruction is implemented with parallelized computing to pursue real-time particle tracking.
- We are using this approach to study local particle motion around vibrating flat surfaces.