Investigation of smoothing operation in 3-D reconstruction for Plenoptic PIV

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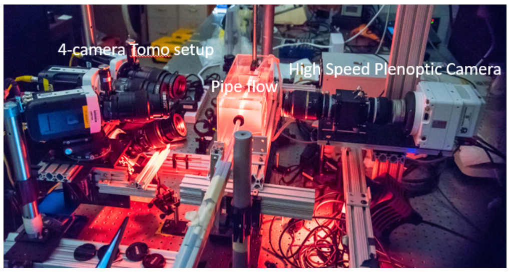
This paper investigates the effect of smoothing operation in 3D reconstruction using a plenoptic camera. A plenoptic camera - also known as light field camera - features a commercial off the shelf camera with added microlens array (MLA) behind the imaging lens, directly in front of the sensor. The main lens focuses the light to the MLA plane, where each microlens then re-directs the light to small regions of pixels behind, each pixel corresponding to different angle of incident (T. Fahringer (2015)) (Adelson and Wang (1992)). Thus, MLA encodes angular information of incident light rays into the recorded image that assist to acquire 4D information (u,v,s,t) of light-field including both position and angular information of light rays captured by the camera (Ng et al. (2005)) (Adelson and Wang (1992)).

Four-camera tomographic particle image velocimetry (tomo-PIV) is the current standard for 3D flow velocimetry. Plenoptic PIV represents an alternative velocimetry technique, with ability to perform 3D measurements with as few as a single camera, which is made possible as around $\sim$100 independent perspective views with mutual parallax can be decoded from a single plenoptic image Hall et al. (2018). In addition, plenoptic PIV also allows notable advantages like larger depth of field and suppressed propensity to ghost due to large number of perspectives available (Tan et al. (2020)). Thus, single camera plenoptic reconstruction is unique to the multi camera tomo reconstruction with large number of available perspective over small angular range.

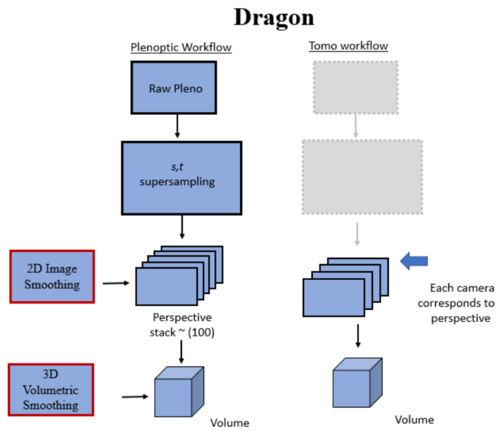
This paper analyzes the effect of smoothing in plenoptic reconstruction based on practices in multi-camera tomo reconstruction. This includes 2D smoothing the image before reconstruction and 3D smoothing the volume during reconstruction. The image smoothing involves 2D convolution operator used as a point-spread function used to smear the pixel intensity. Similarly, 3D smoothing involves the blurring the voxel intensity in 3D volume using a 3D Gaussian convolution operator. The 3D smoothing is performed between each MART iteration. Smoothing helps to obtain smooth solution, suppressing unwanted noise and ghosts while making the particle distinct (dav (2019)).

First, the performance of plenoptic PIV is compared against a multi-camera tomographic system. A simultaneous single camera plenoptic PIV and 4-camera tomographic PIV is set-up to observe a simplified flow-field of flow through a pipe in order to characterize the performance of plenpotic PIV against tomo-PIV 1(a). Both camera were time-synchronized to observe the flow field simultaneously, and aligned in identical coordinate system. For the direct comparison of plenoptic and tomographic system, a 3D reconstruction code that can accommodate both types of images is required. A version of our in-house plenoptic PIV processing code, called "Dragon", was used for this purpose. For this study, the code suite was modified such that four conventional non-plenoptic images could be fed into the algorithm for tomographic reconstruction. The plenoptic dragon and modified multicamera tomo dragon workflow is shown in figure 1(b). This modified version of Dragon is also compared against the state of art multi-camera tomo-PIV commercial software "LaVision DaVis".

Figure 2 shows the 3D particle field from Dragon single camera plenoptic reconstruction, Dragon 4-camera reconstruction and DaVis 4-camera reconstruction. The DaVis particle field seems particularly smooth and distinct and is able to suppress the ghost formation efficiently. The particles from plenoptic reconstruction seems quite stretched along depth as compared to to particles from tomo-reconstruction because of low angular difference between end perspectives. The tomo reconstruction field has visibly noticeable ghost particle, which is diminished in plenoptic reconstruction. The large number of perspectives

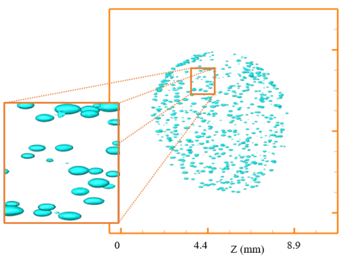


(a)

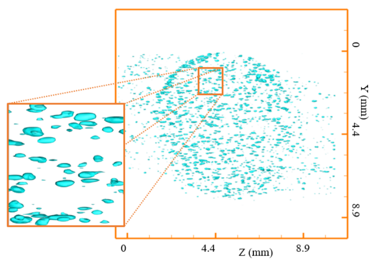


(b)

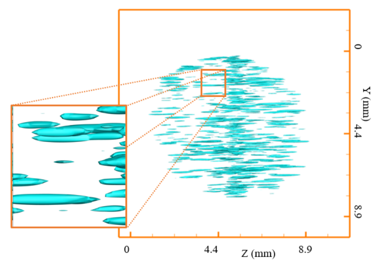
Figure 1: (a) Simultaneous 4-camera Tomographic PIV and single camera Plenoptic PIV setup (b)Plenoptic-Dragon workflow vs Tomo-Dragon workflow



(a)



(b)



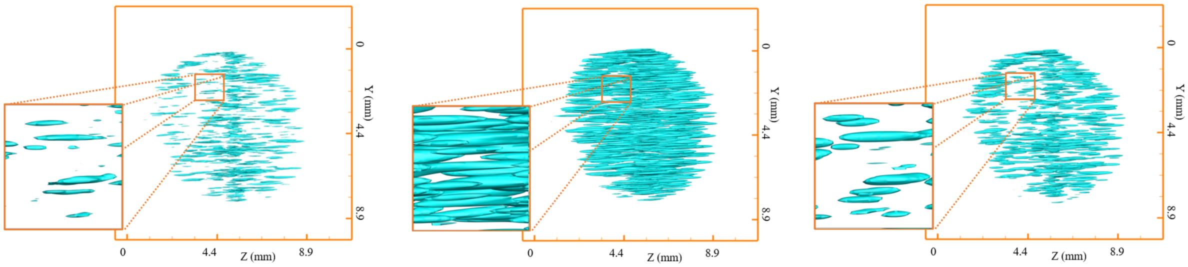
(c)

Figure 2: Comparison of reconstruction using: (a) DaVis 4-camera tomo reconstruction, (b) Dragon 4-camera tomo reconstruction and (c) Dragon plenoptic reconstruction

available for plenoptic reconstruction suppresses the formation of ghosts.

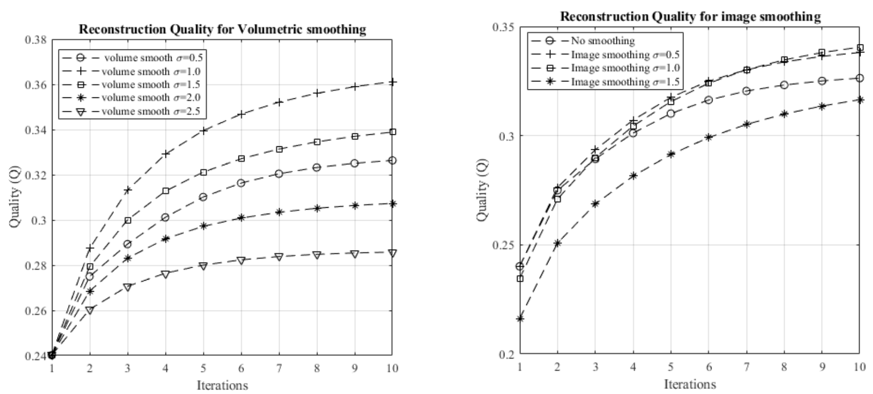
In order to improve the reconstruction in plenoptic particle field, the various smoothing operations were performed based on either smoothing the image or smoothing the volume between iterations. Figure 3 shows the comparison of image based smoothing and volumetric smoothing on plenoptic reconstruction field. It is evident that, the both smoothing operation suppresses the formation of noise in the volume. However, the image based smoothing is observed to enhance the particle size significantly as compared to volume based smoothing.

For quantitative analysis of the effect of smoothing on noise in reconstructed volume, a pair of synthetic plenoptic particle images representing a vortex ring flow was generated with 8500 particles and 10 percent gaussian noise added to it. This was then reconstructed to form a 261*261*261 cubic volume with different smoothing parameters. The effect of smoothing was then observed in terms of reconstruction quality and error in vector fields.From figure 4 it is inferenced that, both smoothing the image and the volume improves the reconstruction quality of plenoptic reconstruction. However, if the smoothing parameter is further increased, the reconstruction quality drops. This is in line with effects seen in multi-camera tomographic reconstruction. Since the plenoptic reconstruction is unique in available information, further tests to identify best practices in plenoptic reconstruction based on general practices in multi-camera tomo reconstruction is desired.



(a) (b) (c)

Figure 3: Plenoptic dragon pipe-flow reconstruction with different smoothing operation: (a) Normal MART (b) Images smoothed with $\sigma = 0.5$ (c) Volume smoothed with $\sigma = 1.5$



(a) (b)

Figure 4: Synthetic vortex ring reconstruction quality for different smoothing operation: (a) volumetric smoothing with different σ (b) image smoothing with different σ.

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