IMPROVEMENTS IN VOLUMETRIC PARTICLE RECONSTRUCTION

APPLICATION NOTE INSIGHTV3V-4G-001 (A4)

Volumetric 3-Component Velocimetry

Volumetric 3-component Velocimetry (V3V) is a photogrammetric imaging technique used to calculate high-resolution measurements of three-dimensional velocity within a volumetric region. When three-dimensional particle tracking is used, a critical step in the velocity determination is the reconstruction of particle locations within the volume. V3V utilizes a calibration target and a polynomial mapping in order to match particle images from multiple cameras, to reconstruct real-world particle locations. The technique has been described extensively in Pereira et al (2000) and Troolin & Longmire (2010). This application note describes several recent advances in 3D particle detection.

Weak Particle Reconstruction (WPR)

WPR is a tool used to address lighting non-uniformities. In any photogrammetric set of images, a given particle, viewed from multiple angles, will have different intensities depending on which view of the particle is chosen. There will also be situations where a particle intensity threshold is chosen, so that some of the views will be above the threshold and one or more below the threshold. Particles with peak intensities below the threshold are often termed *weak particles*, whereas those above the threshold are termed *strong particles*. Usually, weak particles are not used during particle reconstruction due to the chance that they could be associated with noise in the image, rather than actual particles. However, since V3V uses particle images from multiple cameras, it is possible that the same particle may be strong in all the images except one; normally, this particle would not be identified. WPR keeps track of weak particles, and if a match is not found, the pool of weak particles is scanned for a potential match.

Neighbor Tracking Reconstruction (NTR)

NTR is a tool used to recover particles that were unsuccessfully tracked from one frame to the next. Consider the case where two particles are nearby each other in x, y, and z. One of the particles is successfully tracked, and the other is not. NTR uses the displacement information from the successfully tracked particle as an initial guess for the displacement of the un-tracked particle. This initial guess provides a search location for the algorithm to recover an untracked particle. A schematic representation of the NTR method can be seen in Figure 1. The successful tracking of two particles (A and B) is seen on the left. On the right side the case is shown where particle B is tracked successfully, but not particle A. The displacement information from nearby particle B is used to provide a search location for particle A.

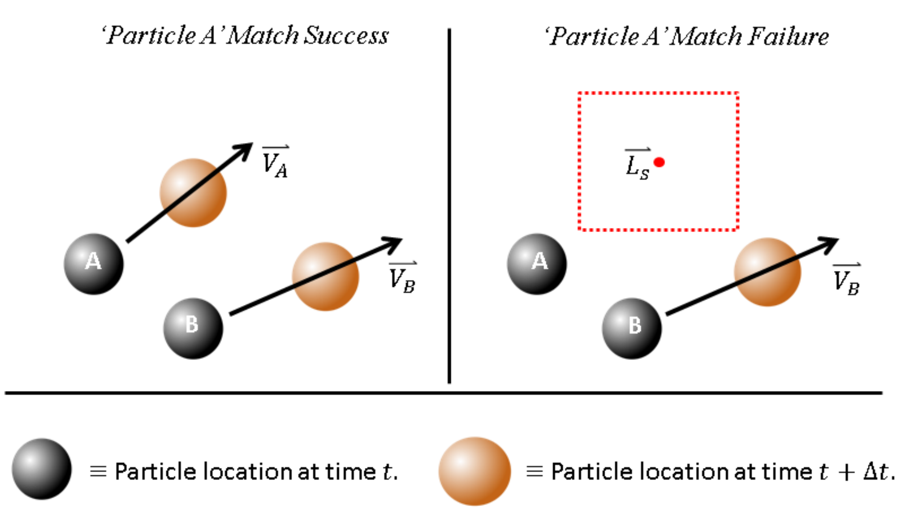

Figure 1. An illustration of Neighbor Tracking Reconstruction method.

Results

Weak Particle Reconstruction (WPR)

As a verification of the WPR method, we have taken raw experimental images from the work of Troolin & Longmire (2010), as shown in Figure 2a, and artificially reduced the image intensity by a factor of three for *a single image* (the image from the second aperture) as shown in Figure 2b (highlighted with red), so as to simulate non-uniform lighting among the three photogrammetric views.

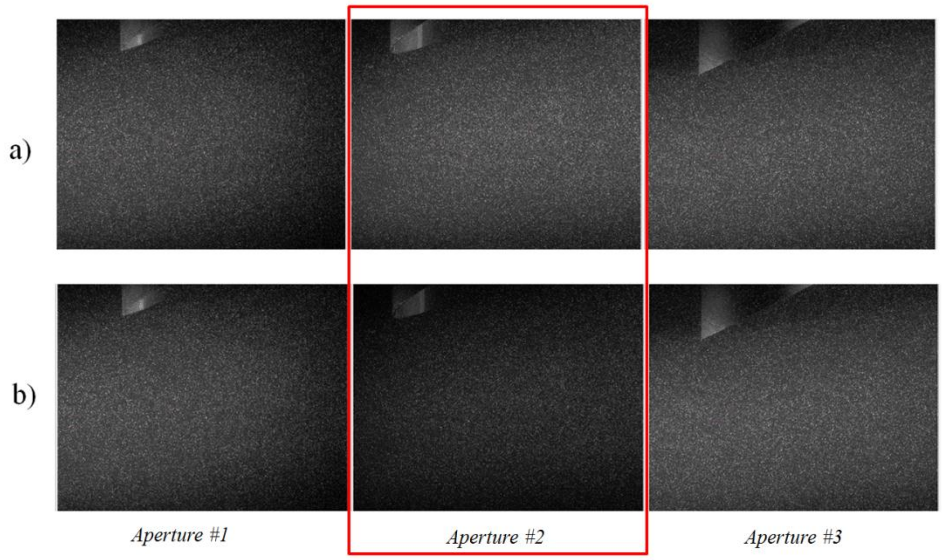

Figure 2. Experimental data from Troolin & Longmire (2010). a) Original, raw images. b) Image from aperture #2 has been artificially dimmed by a factor of three.

Using these two image sets, we conducted triplet reconstruction three different ways:

- **Standard Tracking Method:** Aperture #2 intensity reduced by factor of three. Particle identification intensity threshold of 400. No WPR method.
- **Weak Particle Reconstruction:** Aperture #2 intensity reduced by factor of three. Particle identification intensity threshold of 400, with WPR threshold of 132 (i.e., 400/3).

Table 1 details particle image counts in each aperture's image and the corresponding number of reconstructed triplets for each case. As a result of WPR, the lost triplets due to a non-uniform lighting were recovered (and more), as approximately 24k triplets were found.

Table 1. Particle images per aperture and total number of reconstructed triplets

	Standard	WPR
Right Aperture # Particles	16,363	63,739
Left Aperture # Particles	32,947	42,195
Top Aperture # Particles	43,633	81,934
# Triplets Reconstructed	11,462	23,844

Neighbor Tracking Reconstruction (NTR)

As a preliminary assessment of the NTR method, we reprocessed experimental data from six in-house cases. Of particular importance to this assessment was to quantify the increase in reconstructed triplets. Table 2 details the results of NTR by reporting the numbers of triplets reconstructed with and without NTR. On average, NTR recovers approximately 5% more triplets that had not been identified during the initial triplet search.

Table 2. Percentage increase in reconstructed triplets from six experimental cases using NTR

	#Reconstructed Triplets		
Case ID	**Without NTR**	**With NTR**	**% Overlapped Particles**
1	27,552	28,935	4.8%
2	16,504	16,639	0.8%
3	46,514	47,905	2.9%
4	124,553	136,630	8.8%
5	13,414	14,053	4.5%
6	84,003	90,571	7.3%
Average			**4.9%**

Both WPR and NTR increase the likelihood of identifying and tracking more particles. For more details concerning these methods, please consult:

Boomsma A, Troolin D, Lai W (2015) "V3V Volumetric PIV: New Developments in Particle Reconstruction," *11th International Symposium on Particle Image Velocimetry – PIV'15*, Santa Barbara, CA, USA, Sept. 14-16, 2015.

References

Pereira, F., et al. "Defocusing digital particle image velocimetry: a 3-component 3-dimensional DPIV measurement technique. Application to bubbly flows." *Experiments in Fluids* **29.1** (2000): S078–S084.

Troolin, Daniel R., and Ellen K. Longmire. "Volumetric velocity measurements of vortex rings from inclined exits." *Experiments in Fluids* **48.3** (2010): 409–420.

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