AUTO-CALIBRATION RECONSTRUCTION FOR VOLUMETRIC 3-COMPONENT VELOCIMETRY (V3V)

APPLICATION NOTE INSIGHTV3V-4G-002 (A4)

Auto-Calibration Reconstruction

Volumetric 3-component Velocimetry (V3V) is an optical technique that uses three or more cameras to determine the displacements of particles in a volume over a given time in order to resolve the velocity at thousands of points within the volume simultaneously (see Periera, 2000 and Troolin & Longmire, 2010). To do this, it is important that the exact locations of the particles are identified, so that the displacements can be accurately determined. The three-dimensional location of each particle is performed via triangulation using a mapping formulated during calibration. When calibrating V3V, a target with a known dot spacing is traversed through the measurement volume and images are recorded. Errors could occur in the calibration process, which could then propagate through the subsequently acquired data.

The ACR method addresses reconstruction failure due to calibration error by comparing the projections of reconstructed triplets (onto image planes) and the original particle images of those triplets. The ACR method is an extension of the stereoPIV auto-calibration first described by Bjorquist (2000).

The goal of the ACR method is to modify an existing calibration (or mapping function) to account for errors therein, for example, the physical translation of a camera or camera lens between the time of the calibration and the time during which velocity data is captured. Errors due to calibration can be calculated by projecting already reconstructed triplets in three-dimensional space to each aperture's image plane. The resulting pixel location on the image plane is subtracted from the triplet's original particle image location. This difference is termed an error vector, $\vec{e_i}$, where the subscript i refers to the aperture number. This process is illustrated in Figure 1. In volumetric Particle Tracking Velocimetry (PTV), the reason that the original particle image does not overlay with the projected image is because the three-dimensional location is not solely determined by just a single particle image in a single aperture image frame. Instead, its 3D position is determined by three particle images, each of which will have a slightly different location in real-world space, as calculated from the calibration (recall that a triplet is created when particles overlap *within some tolerance* in three-dimensional space).

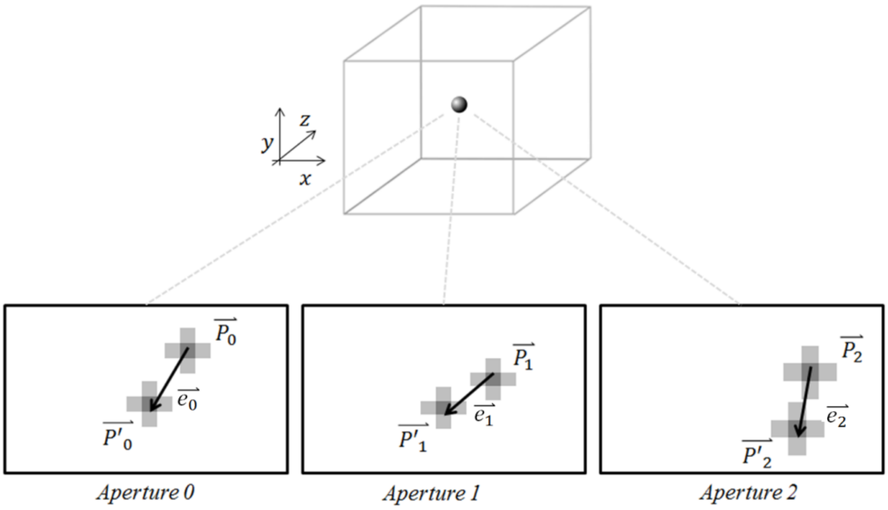

Figure 1. A particle in three-dimensional space has original particle image locations $\vec{\boldsymbol{P}}_i$, though the projection of the particle on to each aperture frame is denoted by $\vec{\boldsymbol{P}}'_i$.

The procedure detailed in Figure 1 is repeated for every reconstructed triplet. To correct the calibration, ACR utilizes a statistical analysis of the error vectors to calculate local average error vectors at each calibration plane, which are then used to correct the calibration. Multiple passes of the method can occur, in order to drive down error.

Results

Experimental data from a fully developed turbulent channel flow was used to perform a preliminary performance test of the ACR method's ability to reduce calibration error. Figure 2 displays the local y-component of calibration error (x-component was similar, but is not shown) at arbitrarily chosen sample points within the volume that were uniformly spaced at each calibration plane. Each row (i.e., a, b, c) in Figure 2 refers to a particular camera aperture, while each column refers to the number of ACR passes that were performed. Without ACR, the mean y-component of error is approximately 0.5 pixels for apertures #0 and #1, but only 0.1 pixels for aperture #2. The calibration error decreases during each ACR pass, ultimately reducing to ≤ 0.1 pixels for each aperture.

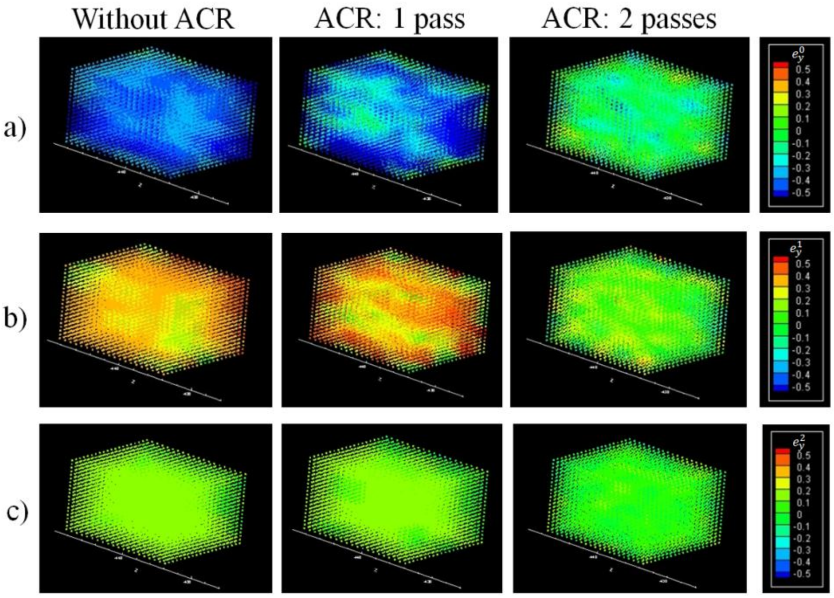

Figure 2. a) Aperture #0; b) Aperture #1; c) Aperture #2. Arbitrary sample points uniformly distributed at each calibration plane. Points are colored by the local y-component of error (pixels).

For more detailed information on the ACR method, consider reading the following paper:

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

Bjorkquist, Daniel C. "Stereoscopic PIV calibration verification." (2002). *11th International Symposium on Application of Laser Techniques to Fluid Mechanics*, Lisbon, Portugal, July 08–11, 2002.

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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USA **Tel:** +1 800 874 2811
UK **Tel:** +44 149 4 459200
France **Tel:** +33 1 41 19 21 99
Germany **Tel:** +49 241 523030
India **Tel:** +91 80 67877200
China **Tel:** +86 10 8219 7688
Singapore **Tel:** +65 6595 6388

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