Volumetric correlation PIV to measure particle concentration and velocity of micro flows

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Volumetric-correlation particle image velocimetry (VPIV) is a new technique that provides a 3-dimensional 2-component velocity field from a single image plane. This single camera technique is simpler and cheaper to implement than multi-camera systems, and has the capacity to measure time varying flows (Fouras et al., 2009). Additionally, this technique has significant advantages over other 3D PIV velocity measurements most notably in the capacity to measure highly-seeded flows. Highly seeded flows, often unavoidable in industrial and biological flows, offer considerable advantages due to higher information density and better overall signal-to-noise ratio allowing for optimal spatial and temporal resolution. Here we further develop VPIV adding the capability to measure concentration and increasing the robustness and accuracy of the technique, without requiring volume scanning, particle tracking and stereo cameras as available PIV techniques.

1. VPIV for velocity and concentration measurements

From a pair of image windows containing particles distributed throughout the flow depth, volumetric auto-correlation is defined as the auto correlation of the same image window, and volumetric cross-correlation as the cross correlation of two image windows. The volumetric (auto or cross) correlation can be considered as the summation of particle correlations at all z-positions throughout the flow depth.

Our study shows that the absolute intensity of particle image correlation is linearly proportional to number of particle, i.e. particle concentration. As particle concentration affects the correlation intensity, the volumetric (auto or cross) correlation is not just a summation of correlations at all z-positions but as a summation of the multiplications between correlations and particle concentration at all z-positions. As a result, volumetric auto-correlation can be considered as a function of particle concentration, and volumetric cross-correlation as a function of velocity distribution and particle concentration.

To measure particle concentration, a least-squares optimization (Levenberg-Marquardt algorithm) is employed to extract particle concentration distribution in the z-direction from a given volumetric auto-correlation. A similar least-squares optimization is also employed to extract velocity distribution in the z-direction from a volumetric cross-correlation and the obtained concentration distribution. By using concentration information, velocity measurement obtained from a volumetric cross-correlation would not contain bias error as shown in our previous experimental work (Fouras et al., 2009).

The ability to measure particle concentration in the z-direction is a unique feature of our new measurement method, without requiring stereo cameras and particle detection (hence limited to low particle overlap and low seeding densities) as required by other available methods.

2. Experimental results

A simple micro-channel experiment was conducted. Below are the concentration and velocity measurement results calculated from a single image window:

![Concentration and velocity measurements](image)

**Fig. 1** Concentration and velocity measurements at the middle of channel width, y = 0. **a)** Measured particle concentration from a auto correlation peak. **b)** Volumetric flow field in 3D view (\(z' = z - z_0 - H/2\)) from an image region. In the central plane (\(y=0\)) parabolic profiles are clearly evident. As expected, modest variation of flow profile on perpendicular plane (\(z'=0\)) with maximum velocity at \(y=0\) reducing toward walls at \(y=\pm 500\)um. In **b)** every second vector is skipped in the z direction.

References