3D micro-scale velocimetry methods: a comparison between 3D-µPTV, stereoscopic µPIV and tomographic µPIV

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While most microfluidic devices have a relatively simple and two-dimensional geometry and the flow in most microfluidic applications is laminar or even creeping, the evolving flow structures in such a microfluidic device can be of complex three-dimensional nature. A typical example is a T-mixer operated at Re > 100, where the interaction of the two inflows creates a strongly three-dimensional laminar flow, which results in an increased contact surface and as a consequence in improved diffusive mixing.

In order to investigate those flows we developed a three dimensional microscopic PIV system (Lindken et al. 2006). The experimental set-up of the stereo-velocimetry system is shown in Fig 1. The stereoscopic viewing is calibrated by means of self-calibration on the particle images (Wieneke 2005). This recording technique provides detailed and accurate stereoscopic measurements of the flow in a volume. These measurements can be used for different evaluation techniques.

1.) Three-dimensional micro particle tracking velocimetry (3D-µPTV) determines the displacement of individual tracer particles in a flow volume. The observation volume is determined by the depth of focus of the imaging lens. In order to map the flow in a deep volume, a large depth of focus is favourable, which is achieved with low NA lenses. Unfortunately, low NA lenses have a lower resolution. This results in the restriction to relatively large tracer particles of 1-µm diameter. The large depth of focus of the imaging system offers the possibility to capture the flow over the depth of the channel at one instant of time.

2.) Stereoscopic microscopic Particle Image Velocimetry (stereo-µPIV) combines the camera arrangement of large-scale stereo-PIV with the illumination procedure used in µPIV. The flow is volume illuminated and the depth of correlation determines the depth of the measurement region. In contrary to 3D-µPTV a small depth of correlation is favourable. The use of a suitable stereomicroscopy lens resulted in a depth of correlation of about 15 µm, which is sufficient for most applications, but a smaller depth of correlation would be favourable.

3.) Tomographic µPIV uses the same illumination technique as 3D-µPTV or stereo-µPIV. The measurement volume is divided in voxels and the intensities of all voxels are reconstructed using a MART tomographic reconstruction algorithm (Elsinga et al. 2005). The voxels then are correlated with a three-dimensional correlation function. We plan to show first trail measurements on tomographic PIV from stereoscopic recordings similar to those used for µPTV and stereo-µPIV.

Stereoscopic µPIV measurements provide all three components of the velocity vector in a two-dimensional plane (of a finite thickness). A full 3D measurement is achieved by scanning in the direction normal to the measurement plane. The use of piezo-driven actuators allows precise positioning (accuracy ~50 nm) and fast scan rates (up to 100 Hz). Fig 3 shows the 3D scan obtained with stereo-µPIV.

3D scan of the velocity distribution in the mixing zone of the microfluidic T-mixer at Re = 120. The data is obtained with stereo-µPIV. The z-axis is stretched 10 times for better visibility of the data. The measurement planes separated by are 22 µm. The depth of the individual measurement plates is 15 µm.

Fig. 1: Schematic of the experimental set-up. The upper half shows the measurement system, the lower half shows the microfluidic set-up.

Fig. 2: 2D representation of the 3D velocity vectors obtained by µPTV. The sum of 20 measurements is plotted in one frame. The detail on the right hand side shows the high shear region.

Fig. 3: 3D scan of the velocity distribution in the mixing zone of the microfluidic T-mixer at Re = 120. The data is obtained with stereo-µPIV. The z-axis is stretched 10 times for better visibility of the data. The measurement planes separated by are 22 µm. The depth of the individual measurement plates is 15 µm.